

# ECOLOGICAL EFFECTS OF ACUTE OIL SPILLS

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MASTER THESIS 30 CREDITS 2010



## **Preface and acknowledgements**

This thesis was a part of the Master programme in Environment and natural resources at the University of Life Sciences. The thesis presented is a literary study of the ecological effects of acute oil spills. The thesis seeks to provide information on what affects spill situations and the ecological effects seen in the context of the Norwegian environment and the possibility for spills along the coastline.

Thank you to my supervisors during this process, Bjørn Olav Rosseland and Vidar Selås for all the help, feedback and guidance. Special thanks to main supervisor Bjørn Olav Rosseland for inspiring and good feedback.

To fellow students at UMB, thank you for inspiration, feedback and support.

I am deeply grateful for all the support and encouragement from friends and family, thank you very much.

To Hans, thank you for all your support, encouragement, patience and love.

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Ås, December 2010

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## **Abstract**

The coastal ecosystems are under constant pressure from natural and anthropogenic sources. The interactions between organisms and their environment is a complex myriad of changes and responses making impacts from acute pollution events both evident and subtle. Some ecosystems may be more resilient than others, and are able to withstand pressure to a great extent. Other, vulnerable systems may be very fragile and susceptible to impacts from outside events. Oil pollution is a threat to the ecosystems, resilient or not, as the effect an oil spill has on the environment cannot be predicted. The complexity of a spill situation are dependent on spill size, oil type, waves, weather, temperature and many other factors that not only affect the spill but also the ecosystems and organisms at risk. The acute effects from a spill are more easily detectable than long term sublethal effects. Persistence of oil in the environment may be a source of long term exposure to the organisms affecting growth, reproduction, oxidative stress, and in turn mortality. Some biological markers (biomarkers) have been developed to measure exposure to Polycyclic Aromatic Hydrocarbons (PAH), an oil component, in the organism. Biomarkers of Cytochrome P450, bile metabolites and DNA adducts have been detected in organisms after oil exposure. However, there is never only one pollutant present in the environment and attributing one effect to one pollutant may be very difficult. The pollutant may in turn affect each other in various ways. An oil spill is typically causing multiple stressor effects. This makes the need for accurate methods for attributing effects to pollutants great. The aim of the thesis was to evaluate the ecological effects seen after oil spills and which factors affected the outcome. The long Norwegian coastline has a high risk of oil spills from ships, and it is important to understand the spill situations to understand the impact it could have on ecosystems in Norway.

Key words: ecological effects, pollution, oil spill, PAH, Cytochrome P450, environment

## ***Chapter 1: Introduction***

### **1.1 The oil spill situation today**

Coastal ecosystems are intricate and dynamic systems in constant change consisting of hierarchically organized species related in a complex network of interactions. The organisms interact not only with each other but with their environment, and are under continuous influence of the biological, chemical and physical properties of their surroundings (Harwell & Gentile 2006). Changes in the environment may originate from anthropogenic sources as well as from natural, and acute pollution situations may threaten ecosystems (Eggen et al. 2004). The effects of these impacts may depend on the resilience and condition of the ecosystem, as well as already existing pressure (Harwell & Gentile 2006).

Over the years there have been a great number of oil spills with severe effects on the environment. The recent events of the BP oil spill in the Gulf of Mexico (2010) have put this issue back on the agenda. The oil platform Deepwater Horizon exploded and sank and caused a massive continuous blow-out from the well that lasted for around three months, lead to a state of emergency in some parts of the USA (Albaigés et al. 2006; Gabbat et al. 2010). The Deepwater Horizon blow out has grown to become the most extensive spill in our time (Griffin 2010). All the effects and impact of this accident has yet to be seen.

The Exxon Valdez oil spill (EVOS) in Alaska in 1989 was the most extensive spill to the marine environment in U.S history (Paine et al. 1996). The spills of Erika (1999) on the coast of France, and Prestige (2002) off the coast of Spain also had great effects that have been studied in the aftermath of the accident (Albaigés et al. 2006; Claireaux & Davoodi 2010). Large quantities of oil was also released into the environment as an act of war during the last part of the Gulf War (1991) (Bejarano & Michel 2010). These historical spills and the effects seen, provides scientists with an area of research that can provide us with knowledge and information that can hardly be duplicated in a laboratory.

Oil spills in Norway have been fairly minor compared to the extent, seriousness and effects of the accidents mentioned above. Norway has 57000km of coastline (Gjøsæter et al. 2010),

consisting of fjords, beaches and rocky shores (Gjøsæter et al. 2010). The nature along the coast is spectacular and consists of various nature types that may be classified as rare or threatened, and many areas have been protected as marine protection reserves (Gjøsæter et al. 2010). Daily, many ships travel along the Norwegian coastline, which alone makes a risk in an oil spill accident. Also, crude oil is transported from Northern Russia along the Norwegian coastline (Faksness & Brandvik 2008). The traffic along the Norwegian coastline is predicted to increase in the years to come, increasing the risk for a spill incident (Dragsund et al. 2004).

## 1.2 Previous oil spills in Norway

During the last 20 years there have been about 22 accidents resulting in oil spills along the Norwegian coastline (WWF 2010). The latest accident was the cargo ship *MV Full City*, which ran ashore on Saastein by Langesund, in the County of Telemark in July 2009. Damages to the ship caused an oil spill of an estimated 300 tonnes that affected a large part of the surrounding coastline (PricewaterhouseCoopers 2010). Oil from this accident was found in 190 different locations at 70 km of coastline, in three Counties (Telemark, Buskerud og Aust- Agder). In the spring/summer of 2010 most of the areas affected in the accident were given a “clean bill of health” by the Norwegian coastal administration (Norconsult 2010).

## 1.3 Oil Types

When considering the potential a substance has to cause harm, it is important to consider whether it can be toxic or not. This was a topic as early as the 15<sup>th</sup> century, when Paracelsus stated that “all substances are poisons; there is none that is not a poison. The right dose differentiates a poison and a remedy” (Walker, C.H et al. 2006).

Oil consist of many different components, and may be crude or more or less refined. There are many different types of oil ranging from very light oils, to heavy crude oils depending on the number of carbon atoms in the hydrocarbon-chain (Boyd et al. 2001). The oil has a low weight and do not readily mix with water (hydrophobic), causing it to float on water.

Different oil types have different toxicity, and can be divided into different groups based on the properties of spilled oil. Very light oils (gasoline and jet fuel) are very volatile and will evaporate quickly after the spill. This group is also very soluble and have a high toxicity in the water column. Heavier oils (diesel, light crude oil and #2 fuel oil) have moderate toxicity and moderate degree of evaporation, this group may also contain the Polycyclic Aromatic Hydrocarbons(PAH), that are considered to be very toxic to marine animals (Boyd et al. 2001). The heaviest group of oils contains less soluble oil, like asphaltenes. This oil may cause great damage by smothering the organisms and may also persist in the environment for a longer period of time.

For a substance to have an effect on an organism, it needs to be bioavailable. Bioavailability means that the substance is present in a form that is able to enter the organism. The bioavailability is dependent on the physicochemical properties of which the substance is present. Dissolution in water, sorption to particles or oil droplets will all have different bioavailability to different organisms (Baussant et al. 2001).

The most visible effects of spills are oil covered beaches, fouled seabirds and mammals. The recovery of these ecosystems and the species affected may be very slow as can be seen from the EVOS where some of the species did not recover for years after the accident (Bodkin et al. 2002).

#### **1.4 Ecological Effects of Oil Spills**

Chronic effects mean that the organism is exposed to a lower concentration over a longer period of time (O'Hara & Morandin 2010). Even though the effects may not be lethal, the effects may be sublethal, causing reduced growth, abnormalities, reduced survival or reproduction, affecting later population numbers of the species (Carls et al. 2001; Fukuyama et al. 2000). This in turn, may have an effect on the distribution of species in the area affected. Some species may be more sensitive than others to oil pollution, and will disappear from the area or be largely reduced in numbers. Other organisms may be more tolerant to the oil and be able to colonize more of the area, leading to more favourable conditions for some tolerant species because of reduced competition or predation (Peterson et al. 2003). In this way the oil



may have a great impact on the environment and can cause changes to populations and habitats in the affected area. Sublethal effects in different levels of organization can be illustrated as shown in Figure 1. After the EVOS it was apparent that oil may stay in the environment for a very long time, and the effects are both acute and chronic (Peterson et al. 2003).

For organisms, the routes of exposure are direct contact, ingestion, inhalation and absorption, and the effects may be lethal or sublethal. Acute effects are effects seen very shortly after a spill. The most prevalent one may be the death of marine avifauna due to feather fouling from oil. Oil on the feathers of birds causes the barbules on the feathers to clump together. This causes disruption of the birds insulation, making the bird exposed to seawater, and may cause hypothermia or drowning due to loss of buoyancy (O'Hara & Morandin 2010). Also, as the oil is toxic, birds may be exposed through the cleaning of fouled feathers and through the ingestion of contaminated food.

The effects of oil in the environment depends on many factors like type of oil, amount of oil spilled, weather conditions, wave action, temperature, season and bedrock of affected area. With so many factors influencing the outcome, the seriousness of a spill is difficult to predict (Moore 2006). The sediments and bedrock in the area are also significant to how persistent the oil stays in the environment. In soft sediments the oil sorbs to particles and may seep deep into the sediments and stay persistent for a long time. This has been shown both from the Gulf war oil spill (Bejarano & Michel 2010) and several other spills (Bjerregaard 2005). When assessing ecological effects of any pollutant, it is important to look at the system as a whole, and consider the species as subjects influencing and affecting each other, rather than as separate subjects (Peterson et al. 2003). An oil spill may have many serious consequences on the ecosystem affected. As the oil weathers, it may become more or less toxic. Many of the previously mentioned factors will influence the recovery process (Michel & Hayes 1999).

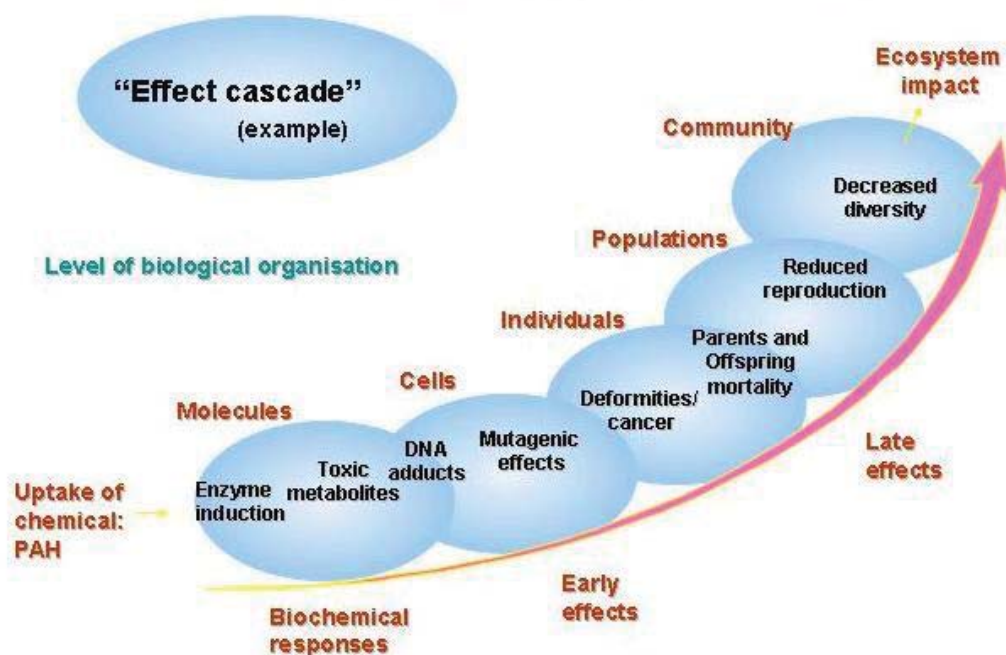


Figure 1. Illustration of sublethal effects on different levels of organization (Download from: <http://iris.no/Internet/akva.nsf/wvDocID/C80B7ECA0C1B6F80C125771C002AFAD9>)

Oil spills provide a ground for research and many of the previous mentioned spills have been studied extensively in regards to short and long term effects, persistence in the environment and many other objectives providing knowledge on this subject. However, lacking data from before a spill situation may make it difficult to attribute changes directly to the spill alone (Paine et al. 1996).

### 1.5 Confinement of Thesis

In this thesis I will describe ecological effects from acute oil spills using previous oil spills and related information. The focus will be on coastal ecosystems and effects to these during a spill situation. Coastal ecosystems, along with ecosystems of the Norwegian coastline will be described to better provide a basis for understanding the complexity of the different ecosystems in combination with an oil spill situation. The thesis does not include off-shore spills that do not involve coastal ecosystems. The effects described in Chapter 7 are effects found after spills and in laboratory experiments. Any secondary effects due to acute oil spills such as financial, social or human effects will not be discussed. Possible effects included will be directly linked to the oil spill itself and not to processes in the clean-up phase such as

damages due to e. g. the use of high pressure water hoses. The use of dispersants during the clean- up process and may alter the properties of the oil (Zahed et al. 2010), however negative ecological effects of these chemicals will not be discussed.

In Chapter 8 a constructed oil spill scenario to give a simplified view of the factors that may influence the outcome of an oil spill in different seasons.

The thesis includes effects seen on marine fishes, marine mammals, benthic organisms, sediment living organisms and other organism in this environment such as zoo- and phytoplankton and also marine birds. It does not include effects to mainly terrestrial animals.

## ***Chapter 2: Materials and methods***

### **2.1. Methods**

This thesis is based upon assessing and interpreting available information on the subject of oil spills and effect of oil spills. Important sources are official reports from the Norwegian Governmental and environmental agencies that are involved in Norwegian oil spills. Information from governmental reports in the USA has also been included. The literary search bases used for articles have been Pubmed, ISI Web of Science and Google Scholar. Google was used for reviews and newspaper articles. For any other literature Bibsys was applied.

#### ***The case method***

The case method is a much used method where a scenario is constructed for a fictive situation. The case method will be used for Chapter 8 where I will be assessing possible effects to Norwegian coastline, emphasizing what factors may or may not affect the seriousness of a spill. The case will be based on a fictive scenario of an oil spill from Jæren, Rogaland. The focus will be on the different parameters that impact the spill in scenarios from different seasons. The scenario will implement the information from previous chapters and give a simplified view of a constructed spill situation. The case will not take into consideration efforts of clean-up process that will be initiated during a real spill situation.

### **2.2 Source critics**

This thesis considers a topic that has recently received major coverage in the media. The oil rig Deepwater Horizon blow- out in the Gulf of Mexico on April 20<sup>th</sup> 2010 has underlined the importance of knowledge regarding oil spills. For this reason it is important to review spill situations from a Norwegian perspective and seek to understand the subsequent effects. This thesis focuses on the ecological effects of oil spills to provide information regarding effects of spills and which factors influence the extent of the spill and persistence of oil in the environment. Previous oil spill accidents have been used as models for acute and long term ecosystem effects.

Considering the Deepwater Horizon spill happened not too long ago, the research in this area is still ongoing and for this reason few to none articles have been published. Some acute effects reports are available, but it has been more difficult locating good sources. The long term effects of this accident are thus too early to consider.

### ***Chapter 3: Coastal Region Ecosystems***

“An ecosystem consists of all the organisms living in a community as well as all the abiotic factors with which they interact” (Campbell & Reece 2002).

The coastal zone is the borderline between land and ocean, a place with constant interactions between the fluid and the solid media, with constant change and movement. The interactions and relationship between the organisms are rarely straight forward (Carter 1988). Coastal areas are constantly changing by influence of climate, light, wind, weather and other physical and chemical factors (Gjøsæter et al. 2010). Variations in exposure to previous mentioned factors influence the organisms spread across the habitats (Falk et al. 2010). Rocky shores have a wide distribution of species that differ from those present in other habitats such as soft sediment beaches and kelp forests (Moen & Svendsen 1999). The complexity of the system may be difficult to model or incorporate when studying them, but this always needs to be taken into consideration when dealing with ecosystems (Carter 1988). The understanding of the characteristics of the different coastal ecosystems may facilitate a greater understanding for the impact an oil spill may have on the system.

“Coastal region ecosystems may be in a fine balance and uncontrolled events such as an oil spill may disturb this balance” (Carter 1988).

Tropical regions have approximately five times longer growth season than ecosystems at higher latitude, and are therefore able to support a wider range of biodiversity. In addition to colder climate, the polar and temperate regions may be affected by periodic snow- cover and/ or glaciations and depends on the melting of snow/ ice before a new growth season may take place. As an effect of this the tropical regions are able to sustain higher levels of biodiversity (Campbell & Reece 2002).

Both rocky shores and kelp forests sustain a great number of species as opposed the less rich soft sediment shore. At first glance soft sediment systems may seem less productive than the others, but there is still a great number of specimen of each species (Moen & Svendsen 1999), and the biodiversity may vary greatly from spot to spot depending on e. g. the content of nutrients in the sediments (Bergan 1989). Kelp forests (*Laminaria* sp.) are very rich areas with high production providing shelter for the inhabiting organisms. The area has a high density of crustaceans, gastropods, bivalves and polychaetes and the density of organisms may reach up to 100 000 individuals in one square meter. The kelp forests are estimated to cover approx. 10 000km<sup>2</sup> of the Norwegian coastline, but has over the last years been in decline (Svenning 2005).

### **Rocky shores**

Rocky shores are shores that consist of solid rock and are located in the intertidal zone of the shore. Rocky shores may include many habitat groups such as boulder fields, rock pools, platforms and steep rocky cliffs and because of the great variation in habitats the rocky shores are often very rich in species. The ecosystem itself experiences many different types of exposure from wave action, tidal fluctuations, wind and solar radiation. This makes a very varying habitat and the organisms populating it must adapt to the variations (Heip et al. 2010). Because of this variation and species richness the rocky shores are an important ecosystem to preserve. It also serves as habitat and shelter for newly hatched fish and crustaceans and provides food for birds, sea living mammals and fish.

### **Zonation**

There is an almost universal zonation to the coast. Because of the many different types of tidal exposure along the vertical regions the dominant species form horizontal bonds (Moen & Svendsen 1999). Tidal zones varies along the Norwegian coastline, and the tidal variations during the day may, south of Bergen be less than 0,5m and increasing the further north you go, so that in Tromsø the difference may be approx. 2,5m. This will affect the vertical zonation exposure. The organisms inhabiting the coastline may be planktonic, floating or swimming freely in the sea, or benthos living on or in the substrate (Bergan 1989).

### *Supratidal zone*

The most upper zone is called the supratidal or splash-zone. This zone is exposed to air after tidal retreats, splashing from waves, and sea cover when the tide is high or when storms occur. The salinity may vary greatly from zero to almost 30‰ at the most extreme, as the area is influenced by heavy rainfall and river outlets. The species of this habitat experiences conditions of complete draught and complete coverage of water and therefore needs to be able to withstand these very different conditions (Moen & Svendsen 1999). Some of the species found in this region are sessile animals that attach to the substrate and have low mobility. Many insects and spiders and also crustaceans and bivalves are found in this habitat. Macrophytes that inhabit this region may be algae (mostly brown and green) and some salt tolerant plants (Falk et al. 2010).

### *Intertidal zone*

Located between the upper and lower tide limit lies the supratidal zone is the intertidal or littoral zone. The upper part of this zone is characterized by species adapted to tolerance in temperature and drying and the limiting factor in the lower part will often be predation or competing species. Species that inhabit this zone are exposed to both air and water. This means that they must be able to tolerate very different conditions depending on whether the tide is high or low. Conditions like drying out and being covered with water, different requirements for gas exchange/ respiration and exposure to UV light via the sun light (Carter 1988).

### *Subtidal zone*

Located below the intertidal zone is the subtidal zone which is free of tidal disruption. This zone is therefore more stable and constantly covered with seawater. This means that parameters of temperature and solar radiation is close to constant, hence contributing to a more stable environment for the subtidal organisms (Carter 1988).

### *Sediments*

Sediments may be located at any coastal zone. The sediments are often mixed structures from many sources and may function as a possible sink for nutrients and/ or environmental

pollutants. Short or longer term storage of these substances is common and may be very useful or harmful to the organisms in the ecosystem. The time a substance stays in the sediment may vary greatly. Also, release of nutrients and pollutant may occur at times where e. g. the chemical conditions are in change (Carter 1988). The organisms living in or off the sediments may be affected by exposure to which ever substance is there at a given time. However, the substance needs to be biologically available for it to have an effect on the organism (Carter 1988).



## ***Chapter 4: Area description- Norway***

### **4.1 The coastline of Norway**

“The coastal zone is the space in which terrestrial environments influence marine (or lacustrine) environments and vica versa” (Carter 1988).

Norway has a coastline of approx 57 000 km consisting of many small islands, long fjords and beaches of different kind (Gjøsæter et al. 2010). Norway’s coastal climate is characterized by temperate summers and fairly mild winters (O'Brien et al. 2004). However temperature and light conditions changes with latitude. The coastal zone is a very productive environment, and productivity varies with seasonal change (Falk et al. 2010).

The Norwegian coastline consist of several regions; Barents Sea, the Norwegian Sea, the North Sea and Skagerrak. The long coastline makes room for many different types of nature types and habitats along it, and large variation is seen in the different ecosystems. Habitats may range from rocky shores and gravel beaches to sandy or muddy shorelines or even kelp forests (Moen & Svendsen 1999). Some of the shoreline may also be wetlands. Wetlands are very rare and represent an important habitat as foraging and resting area. As this is a rare habitat it’s also home to species that are quite specific to this habitat. Some of these areas are protected through the RAMSAR convention of 1971 that ensures protection of wetlands that is internationally important. Areas of this characterization are referred to as Ramsar areas (Dragsund et al. 2004).

Some of the areas along the Norwegian coast are considered more vulnerable to human activities than others. Areas important for fish spawning, like Lofoten, Vesterålen and the Barents region is considered to be one of the most productive and cleanest systems in the world. These areas are especially important for cod, Pollock, herring and capelin (Dragsund et al. 2004). Some of the same areas serve important function as nurture and foraging areas for many types of fish and marine mammals. The Barents area has a very high density of marine birds and the area is habitat to many red listed species (Dragsund et al. 2004). Species specific

for a habitat are challenged with the disappearance of habitat and human impact and disturbance. The protection of vulnerable habitats is therefore important to secure their survival. Many habitats along the Norwegian coastline are considered rare and may contain a number of rare, endangered or red listed species. Oil spills add to the already existing pressure of human activities.

### ***Vulnerability and Environmental Risk***

The DNV (Det Norske Veritas) has described environmental risk as the probability that a situation occurs (frequency) combined with the environmental damage (consequence) that situation would cause. A model (MOB model) has been constructed to aid decision makers during the clean-up process after a spill. This environmental vulnerability model (MOB) is utilized to better prioritize protection of the more and less vulnerable areas. In this model, areas or ecosystems are categorized into susceptible classes, or MOB categories, with specific values indicating their vulnerability. The MOB categories values natural resources and range from MOB A= the most vulnerable, MOB B= Medium vulnerable and MOB C= less vulnerable. The Counties in Norway have categorized their areas accordingly as can be seen in Table1. For the counties that did not perform this evaluation the numbers were collected by DNV, based on evaluation from the Marin Ressurs DataBase. When categorized the areas are evaluated to parameters such as natural occurrence, to which extent the resource may be replaced, protective value and vulnerability. The areas may also be assigned different categories for different seasons. The criteria highly valued are also especially environmentally sensitive areas and national and international areas of importance such as Ramsar areas (Dragsund et al. 2004).

Table 1: MOB areas according to county and season, numbers reflect the count of different MOB areas in each category (\*including both autumn/ winter or spring/summer) (Dragsund et al. 2004)

Fylke	MOB A	MOB A	MOB B	MOB B	MOB C	MOB C
	Vinter*	Sommer*	Vinter	Sommer	Vinter	Sommer
Finnmark	30	29	43	43	88	85
Troms	18	23	20	32	23	32
Nordland	10	85	44	164	99	205
Nord-Trøndelag	0	4	8	14	4	7
Sør-Trøndelag	14	20	46	39	37	45
Møre og Romsdal	44	44	57	57	349	349
Sogn og Fjordane	26	64	5	19	15	28
Hordaland	8	33	8	52	21	24
Rogaland	80	100	109	113	182	186
Vest-Agder	7	18	16	27	73	75
Aust-Agder	1	8	11	30	10	11
Telemark	5	5	14	49	15	23
Vestfold	6	7	17	24	52	85
Buskerud	1	1	4	4	3	3
Oslo	2	4	1	0	3	4
Akershus	1	9	7	8	14	14
Østfold	11	12	25	37	9	12

The vulnerability map for oil pollution based on the densities of MOB areas portrays the situation along the Norwegian coastline (Figure 2). The model includes spawning areas for some species of fish, although rated low on the MOB scale without discussing why this consideration has been done (Dragsund et al. 2004). Some species may be considered as more sensitive to oil spills than others, as mentioned by a Risk Group (Risiko gruppen) in a Norwegian governmental report after the Deepwater Horizon spill. The group mentions divers (*Gaviidae* spp.), auks (*Alcinae* spp.), cormorants (*Phalacrocoracidae* spp.) and sea diving ducks as the most sensitive in a spill situation. The groups that are considered to be moderately sensitive are some diving ducks (*Aythya* spp.), petrels (*Hydrobatinae*). Considered less sensitive are skuas (*Stercorariidae*), gulls (*Laridae*), terns (*Sternidae*) and phalaropes (*Procellariiformes* spp.) (Risikogruppen 2010). To demonstrate the different vulnerabilities to different species throughout the year please see MOB list in Appendix I (in Norwegian) (Alpha Miljørådgivning AS 2008).

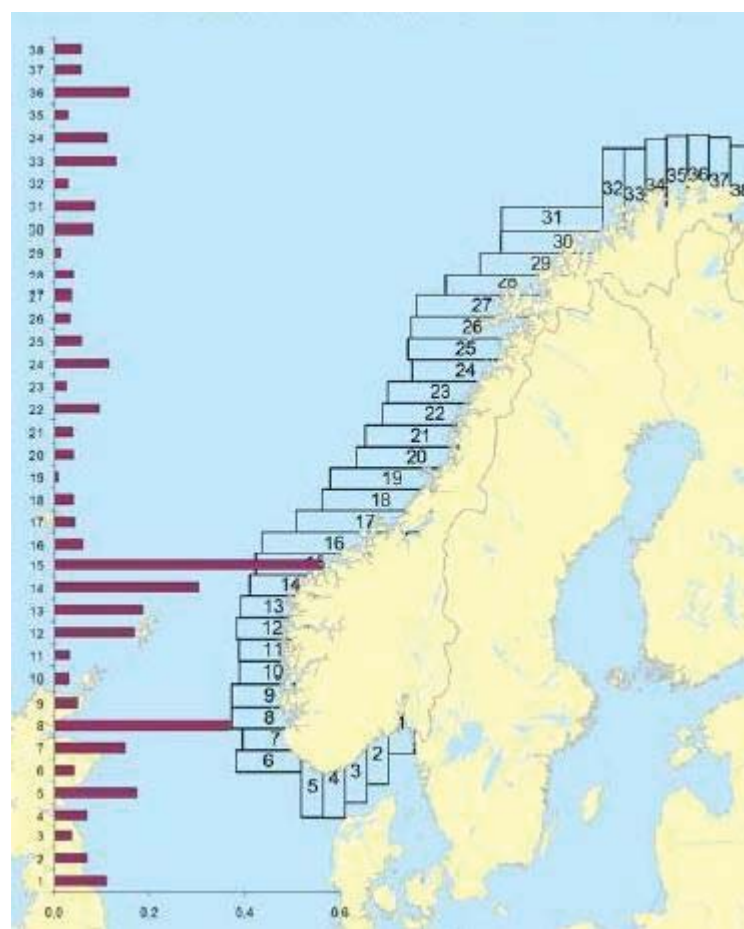


Figure 2: The vulnerability to oil spills from ships for different areas along the Norwegian coastline during summer, based on the MOB model (Dragsund et al. 2004)

## Chapter 5: Oil

### 5.1. General properties of oil

The main components of oil are hydrocarbons.

Hydrocarbons are compounds consisting of hydrogen and carbon (see Figure 3). Oil may contain branched and unbranched forms of alkanes, alkenes, alkynes and aromatic hydrocarbons. It may also contain different elements such as sulphur, oxygen and different metals (Wang & Fingas 2003).

Oil consists of many different compounds used for various purposes. It is important to separate between crude oil and more refined oil products. There is a

natural occurrence of crude oil through seepage from the seabed, and many organisms may be adapted to living in this environment. The extent of this in volume is far greater than the accidental oil spills (Kingston 2002). However, this will not be discussed further. The environment may also contain hydrocarbon from anthropogenic sources and petrogenic sources such as the combustion of fossil fuel (Lee & Anderson 2005).

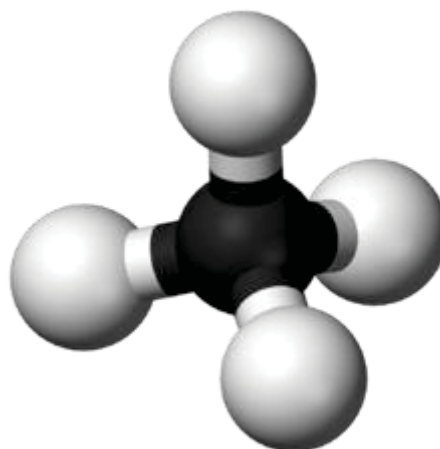


Figure 3: Hydrocarbon molecule, methane (Wikipedia 2010a)

Different crude oils that are pumped up during oil and gas exploration have different composition, containing a mixture of the different hydrocarbon groups and organic compounds. There is different composition of oil from different sources, due to the different conditions in the formation of the oil. Formation from different organic materials and under different geological conditions makes identification of the hydrocarbon source possible (Wang & Fingas 2003). Oil may be light and relatively easily evaporated, while another may be heavier and thus contain different components (Boyd et al. 2001).

Hydrocarbon compounds can be divided in different groups according to their molecular weight (Table 2). The first group is the molecules of the smallest molecular weight, the lightweight hydrocarbons, which contain 1 to 10 carbon atoms. Because of their low molecular weight they are quite volatile, which means that they evaporate quite easily when

exposed to air. They also dissolve easier than the medium and heavier hydrocarbons, but evaporation will be the main weathering process, and very little of the light weight compounds will dissolve in the water (Boyd et al. 2001).

Medium weight hydrocarbons consist of 11 to 22 carbon atoms. Compared to the light weight, these evaporate more slowly. This group of hydrocarbons are the ones that pose the greatest risk to the environment as they dissolve in the water, making them available for the biota. This group contain the potentially toxic PAHs'. PAHs' are hydrocarbons that contain benzene rings, and are normally considered one of the most toxic components of oil. They normally have low water solubility, but may occur frequently in sediments and bound to organic and inorganic particles (Nikolaou et al. 2009). Which are the ones that are thought to have the most negative biological effect when entering the environment (Lee & Page 1997).

Heavy weight hydrocarbons are consisting of 23 and more carbon atoms and these are quite heavy and very difficult to dissolve and evaporate (e.g. asphaltenes). These types of oil have less acute toxicity to the organisms, as it is less water-soluble and therefore less bioavailable. However, they tend to persist longer in the environment (Boyd et al. 2001).

Table 2. Different oil types containing light, heavy and medium weight hydrocarbons, and some main characteristics (Boyd et al. 2001)

Oil type	Components	Relative persistence	Boiling point range
Gasoline	Mostly light weight (>10 C atoms)	1	40°C- 150°C
Fuel oil #2 (diesel)	Light weight and medium weight (10-20 C atoms)	8	33,9°C- 185°C
Fuel oil #6 (bunker)	Mostly heavy weight (25- 50 C atoms)	400	323,9°C- 441,1°C

Crude oils may be distilled in to refined products. The use of different distillation methods and crude oil component gives every refined product a different composition (Wang & Fingas 2003). A common component of both crude and refined oil is PAH.

## 5.2 Toxicity of oil

When conducting toxicity testing of effects of single substances one may test for different endpoints. The “umbrella endpoints” are failure of immune system, disruption in reproduction, genotoxic effects like mutations and increased mortality (Salbu et al. 2005). The use of biomarkers for indication of exposure is frequently used in toxicity testing as the former mortality testing, like  $LC_{50}$ , no longer are to be considered as a method which can be used within the “animal welfare” principle (Rosseland Pers. comm. 2010 ).

## 5.3 Exposure

For a substance to have an effect there are several criteria in this sense needs to be fulfilled. The substance in question must be bioavailable to the organism. Bioavailability means that it is present in a form that can be taken up or be bound to the organism and lead to an adverse effect. When exposed the effects also depends on the exposure time and the concentration of the chemical or chemicals involved (Boyd et al. 2001).

There are many different routes of exposure to toxic substances, depending on the compound. Ingestion, inhalation, direct contact and absorption through the skin may occur alone or in combination and lead to effects (Boehm et al. 2007). Amount of oil exposure to an organism depends on oil type, spill volume, shoreline type, tidal stage and weather conditions (Boyd et al. 2001).

After uptake the pollutant may be distributed throughout the organisms system in various ways. The pollutant may cause a direct toxic effect, be metabolized in the body and detoxified. In some cases metabolites might be more toxic than parent component, it may be stored in the organism or excreted (Walker, C. H. et al. 2006). Biomarkers are frequently used to assess the exposure to pollutants, including PAH in oil.

Biomarkers are “biological responses that can be related to an exposure to, or toxic effect of, an environmental chemical or chemicals” (Peakall 1994)

This may be responses in any hierarchical level, thus some biochemical biomarkers have been identified for use in environmental monitoring. Related to the influence from oil, like biomarkers of activation of Cytochrome P4501A (Hylland et al. 2006), PAH metabolites in bile or DNA adducts found in the liver or blood (Aas et al. 2000). Thus, relate responses in a biochemical or cellular level to population level response is difficult, though some biomarkers may have potential to act as a predictive tool (Hylland et al. 2006). PAHs have been known to induce carcinogenic effect in vertebrates (Reynaud & Deschaux 2006). They are known to cause acute toxicity affecting the metabolic response through the activation of Cytochrome P450, which removes PAH from the tissue while producing reactive oxygen species (ROS). On the other hand ROS will cause breakdown in biomolecules such as DNA (Eggen et al. 2004). An example of Cytochrome P450 activation in seagulls will be discussed in chapter 7.5.

Oil that enters the ecosystem via the sediments may be leached to the intertidal and surrounding water exposing sediment living organisms such as *Polychaeta* spp. or bivalves. These organisms habitat are in or on the substrate, and are there at risk for uptake of oil components from the surrounding pore water (Peterson et al. 2003). Mussels are filter- feeders and come in direct contact with any substance linked to particles that may be present in the water (O'Connor 2002). Oil components may be accumulated in the mussels, as they have little ability to metabolize the compounds (Peterson et al. 2003). This may cause sublethal effects to the organisms itself, and lead to a mobilization of antioxidant defence like increased production of e.g. heat shock proteins (HSP). HSPs' are proteins that are induced to protect the organism in case of environmental stress like oxidative stress, temperature stress and UV stress (Wolfe et al. 1999).

Increased concentrations of oil components can impose effects to organisms at a higher level in the food chain by eating these mussels (Laffon et al. 2006). One example of this is seen after EVOS accident. The Sea Otter (*Enhydra lutris*) population had after a long period of



time, had still not recovered from the accident. This may in part be due to the way of which the Sea otters search for food, by digging for clams and mussels in the intertidal zone. This means they may be exposed to un- weathered oil from the sediments, but also through contamination of oil components via digestion of contaminated clams and mussels (Bodkin et al. 2002). When it comes to investigating pollution in marine waters, mussels as bioindicators for toxic compounds is a common tool (Laffon et al. 2006).

There will always be more than one pollutant present in the environment. Effects of multiple stressors may be difficult to predict (Eggen et al. 2004). For substances that have does not interact but has the same mode of action the effects may be additive ( $1+1=2$ ). For substances that interact with each other the effect if more difficult to predict but effects may be antagonistic ( $1+1=0$ ) or synergistic ( $1+1=3$  or more) (Eggen et al. 2004; Salbu 2009). The effect may lower the organisms' threshold for a substance, and it may be difficult to relate effects directly to this one stressor only (Eggen et al. 2004).

#### **5.4 Fate of oil pollution in the ecosystem**

After the oil has entered the marine environment it is lighter than water and forms a thin “slick” on the surface. A complex weathering process begins soon after the oil has entered the water (Wang & Fingas 2003). The components of the oil that are very volatile will evaporate within a short period of time, leaving the heavier fraction on the surface (Kingston 2002). The oil sheen will be distributed by the current in the water, the wave action and the wind direction. The evaporation after the spill is affected by temperature, solar radiation, wind and the area of the slick exposed (Boyd et al. 2001). As much as 30-50% may evaporate, depending on temperature and composition of the oil (Kingston 2002). In arctic areas with low temperature there will be increased thickness of oil film and less evaporation of volatile compounds. The presence of sea ice and the low temperature will affect the evaporation process negatively. Also, if oil freezes in to the sea ice, when thawing, this may expose organisms to water soluble bioavailable oil components that are potentially toxic (Faksness & Brandvik 2008).

After a short period of time the oil will start to form a mixture or an emulsion, which may contain up to 80% water. This makes the oil mix with water forming droplets of oil in the floating slick, slowing the weathering process (Kingston 2002). Oil may also adsorb to particles in the water and will eventually sink to the bottom and enter the sediments, or hit the shoreline and stick to the substrate there (Boyd et al. 2001). After sinking to the bottom, the oil may penetrate the substrate, making the weathering effects from wave action and other physical weathering processes less efficient. In soft sediments the oil may persist longer than e.g. solid bedrock. Lipophilic substances that associate with particles and enter the sediments, are therefore not bioavailable to the free-swimming or non- sediment living organisms. Figure 4 demonstrates the ways of which the oil enters the environment (Kingston 1997).

Some of the oil will dissolve in the water. This is the fraction that is most bioavailable, and therefore the part that has the potential to cause the most damage. This fraction contains the potentially toxic compounds such as naphthalene, phenantrene and dibenzotriophene (Neff & Stubblefield 1995).

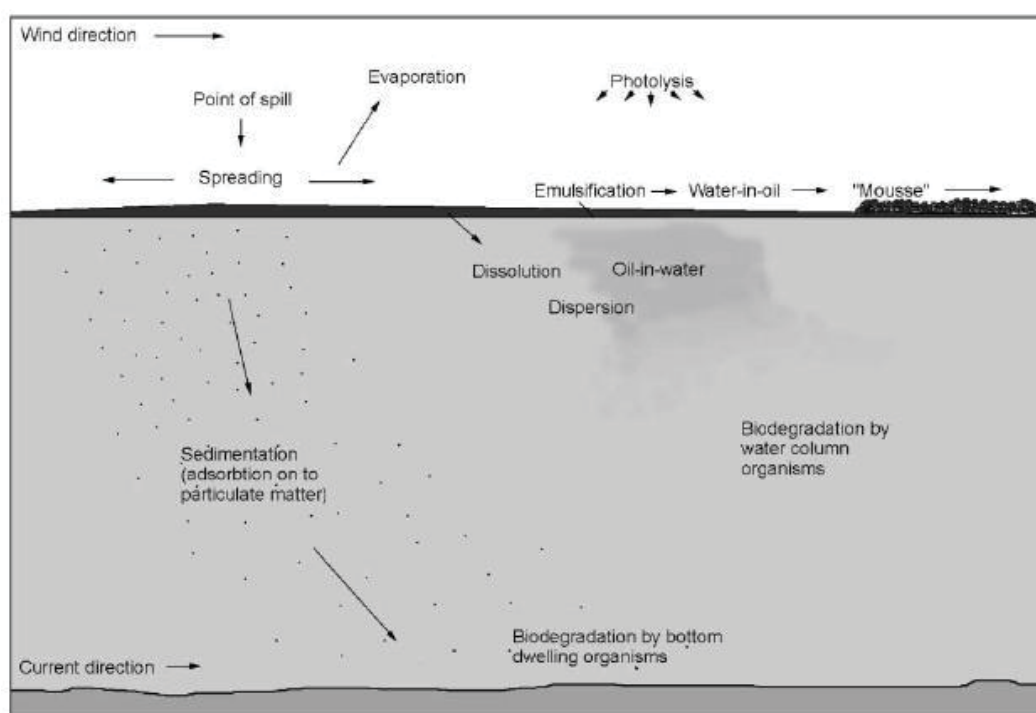


Figure 4: Routes of oil entering the marine environment (Kingston 2002)

Oil that does not enter the substrate, may be exposed to the wind and waves, forming small droplets that can be available to biodegradation from microorganisms (Braddock et al. 1995) or chemical breakdown through photolytic processes. Weathering of oil will be influenced by factors such as bacterial levels in the affected location, salinity of the water, temperature and water level (Wang & Fingas 2003). UV from solar radiation will oxidize the oil through photolysis to produce compounds that may be more toxic than the original oil. The concentration of these components however is still considered too small to have any ecological effect (Kingston 2002). The more intense sunlight present, the more efficient the photolytic process is (Nikolaou et al. 2009).

Lipophilic substances may accumulate in the food chain. The situation for e.g. PAHs is not straight forward as they can readily be metabolized by some fish, mammals and birds. The bioconcentration that may occur would be a through uptake of PAHs via food and the surrounding water (Ruus et al. 2009). However, mussels cannot metabolize oil components, making them vulnerable to bioconcentration (Walker, C. H. et al. 2006).

## ***Chapter 6: Oil spill accidents, background***

### **6.1 International accidents**

Among international accidents, especially the spills of the oil rig Deepwater Horizon and the oil tankers Exxon Valdez, Erika and Prestige had great impacts and have been studied in the aftermath of the accident (Albaigés et al. 2006; Claireaux & Davoodi 2010). Also, during the last part of the Gulf War, large quantities of oil were released in to the environment in the Saudi Gulf (Bejarano & Michel 2010). Each accident is different, and the varying environmental factors, different oil components and clean-up efforts will contribute to different outcomes of each accident. When so many factors is in play, the final severity of the spill e.g. effects on ecosystems or persistence of oil in the environment, may be difficult to predict and knowledge about previous spills may be of great aid to understand the consequences of an oil spill in the future.

The most recent spill was the Deepwater Horizon (British Petroleum) oil spill in the Gulf of Mexico, off the coast of Louisiana. On the 20<sup>th</sup> of April 2010 the Deepwater Horizon caught fire due to gas escape from the well and igniting on the rig's deck. After exploding and burning for approx. 36hrs the rig finally sank, causing the drilling riser from the wellhead to break. This cost 17 peoples' lives and caused a continuous blow- out for approximately three months, making this the largest marine oil spill in the world. The well was closed on the 15<sup>th</sup> of July, but final confirmation of the successfully shut down well was not given by BP until the 19<sup>th</sup> of September 2010 (BP 2010b). The final estimates of how much oil leaked to the environment was estimated to be about 4,9million barrels or 77 billion litres (Bourne 2010). Because the incident happened offshore, quantities of the oil hit the coast of the USA is in more or less weathered condition and as tar- balls. Also, during the spill, over 800 000 gallons of dispersants were applied. This mixture of oil, dispersant, and oil-dispersant complex all have different properties and effects of these to the marine life are somewhat unknown. It may therefore be difficult to separate effects from the oil itself and effects by dispersant (Lubchenco 2010). Figure 5 illustrates the very large area affected by the spill. The impact on the ecosystems is still not established as the accident is of recent character (Lubchenco 2010). Research and restoration programmes have been initiated to fully understand and document effects and rehabilitation of affected areas (BP 2010).



Figure 5: Spread of the BP slick in the Gulf of Mexico, picture taken during the blow-out period (<http://blog.skytruth.org/2010/07/bp-gulf-oil-spill-68000-square-miles-of.html>)

One of the most extensively researched spills is that of the oil tanker Exxon Valdez in Prince William Sound, Alaska in March 1989. It was estimated that approx. 37000 tonnes of Alaskan North Slope Crude oil was spilled in to the water, contaminating a total of 1990km of pristine shoreline (Peterson et al. 2003). The accident happened in an area where some parts were quite secluded and this made the clean-up process difficult. Some of the beaches that were affected were shielded from wave and weather action, slowing down important processes in the oil weathering and removal from the environment. This contributed to the oil staying persistent in the environment for a long time after the accident (Figure 6) (Moore 2006). In combination with low temperatures and the composition of the beaches makes the persistent oil almost non-weathered in the intertidal zone (Exxon Valdez Oil Spill Trustee Council 2010).




Figure 6: Lingering oil in sediments after the EVOS from 2001 (Exxon Valdez Oil Spill Trustee Council 2010)



Figure 6: Lingering oil in sediments after the EVOS from 2001 (Exxon Valdez Oil Spill Trustee Council 2010)

Another accident that was larger than the EVOS but did not experience the extent of damaging effects was the spill of the oil tanker *Braer*. The accident happened in the Shetland

Islands in January of 1993 and some 85 000 tonnes of Gullfaks crude oil was released in to the environment. Due to the wave action and wind the oil was dispersed quickly, and large quantities of the lighter oil types evaporated. The weather prevented any effort to pump the oil or tow the ship to safety. The oil content in the water declined fast, an estimated 35% of the oil ended up in the sub-tidal sediments (Kingston 1997) and only about 1% of the spilled oil ended up on the coast of Shetland (Harris 1993). The effects of this accident were smaller than initially anticipated (Kingston 1997).

During the oil spill from the oil tanker Prestige off the coast of Galicia, Spain in November 2002, 63 000 tonnes of heavy fuel oil leaked into the marine environment (Alonso-Alvarez et al. 2007). PAHs from the spill were observed in the food chain years after the accident, demonstrating the persistence of the oil (Pérez et al. 2010). The Prestige oil was a heavy fuel oil with low solubility, which again resulted in low degree of dispersion and slower degradation. Also, the Prestige oil contained metals like copper, lead and cadmium that could have toxic effect on the biota. Effects from this accident were seen at least until June 2004 (Laffon et al. 2006).

## 6.2 National accidents

In the last 20 years Norway has experienced approx. 22 more or less severe accidents of oil pollution from ships (WWF 2010). The relative recent accidents of *MV Full City* (2009), *Server* (2007), *Rocknes* (2004) and *Green Aalesund* (2000) represent some of the accidents that have affected the coastal environment (Falk et al. 2010). The biggest spill in Norwegian context was the Bravo oil rig blow out in April 1977 (Klif 2010), however this spill did not reach the Norwegian coastline.

In July 2009 the Panama registered cargo ship *MV Full City* ran ashore in Saastein in Langesund, Telemark (Sletner et al. 2010). The ship suffered injuries to the hull and approx. 294 000 litres oil leaked into the marine environment (Sletner et al. 2010). As a consequence oil was registered in 190 places along a 70km coastline (PricewaterhouseCoopers 2010). 39 species of birds were reported to be affected by the spill, with a total number of approx. 2500 individuals (Klungsøyr & Boitsov 2010).

During a storm in January 2007, the cargo ship *Server* ran ashore outside Fedje in Hordaland in, in the nature reserve Hellisøy (Byrkjeland et al. 2008). After the accident approx. 370 tonnes of fuel oil was spilt, creating a slick that spread 170km (Skrede & Jensen 2007) and affected nine nature reserves (Byrkjeland et al. 2008). However, the area closest to the site of the accident was the one that received the most oil contamination (Byrkjeland et al. 2008). Due to high waves and wind conditions it was impossible to prevent the oil from reaching the coastline (Skrede & Jensen 2007). Weather conditions after was considered to be very bad, and for safety reasons, did not support search for affected wildlife. The estimates on affected wildlife is therefore uncertain (Skrede & Jensen 2007).



## ***Chapter 7: Possible effects of oil spills***

Oil spills can lead to adverse effects in an ecosystem. Not only the direct toxic effects on organisms from the oil, but also physical damages like fouling of protective coating, smothering and hypothermia in i.e. birds have been observed (Harwell & Gentile 2006). The effects may be acute or chronic due to long term exposure. Acute deaths of a great amount of marine organisms such as birds, fish and marine mammals may alter the population numbers (Peterson et al. 2003). Further, chronic exposure to oil components in the environment following an oil spill may lead to a series of effects e.g. increased oxidative stress that may lead to degradation of important biomolecules in turn affecting e.g. immune system and in turn many more mechanisms in the organism (Salbu 2009).

Oil spill has been shown to affect a vast range of organisms from plankton algae to marine mammals, all in different ways. The growth of phytoplankton has been shown to be inhibited by stress of crude oil at a concentration higher than 2,28- 5,06mg l<sup>-1</sup>, it was also shown that the phytoplankton were able to restore the growth as the degradation of the pollutant increased. At lower oil concentrations exposure the phytoplankton showed increased growth compared to control samples (Huang et al. 2010). After the Prestige spill, increased growth in phytoplankton was observed some time after the spill, however the reason for this was not discussed. No clear changes could be attributed to the spill, and phytoplankton bloom during the following spring was considered to be unchanged. However, great variations in phytoplankton biomass, short generation time and environmental factors may contribute to mask any direct effects on sensitive species caused by the spill (Varela et al. 2006).

Stekoll and Deysher (2000) investigated rockweed (*Fucus gardneri*) after the EVOS, and found that affected populations had lower reproduction than populations that were not affected by oil. Rockweed plays an important role in the intertidal community, and effects on the rockweed will potentially affect other species in the community in turn (Stekoll & Deysher 2000). Changes in vertical distribution of rockweed (*Fucus spp.*) and subsequently long time of recolonization have also been observed after oil spills (Teal & Howarth 1984).



After the *Braer* spill, the only noticeable change in the species close to the ship wreck was the absence of the limpet (*Patella vulgata*), that normally grazes on algae. This caused green algae, *Enteromorpha* sp., to grow in the area. However, the lack of sufficient evidence of the status before the accident made conclusions of significant change hard to prove (Kingston 1997).

To investigate the presence of a pollutant and monitor recovery of the ecosystem, changes in distribution of different organisms on family and genus may be a useful tool. Gomez Gesteira et al (2003) identified organisms on the genus level in soft- bottom macrobenthic communities when investigating changes after the Amoco Cadiz spill and Aegean Sea spill. Changes in the community before and after the spill showed that more oil tolerant (e.g. polychaetes), opportunistic species was more abundant after the spill, and that sensitive species (e.g. amphipoda sp.) that had dominated the area previously were missing from the area (Gomez Gesteira et al. 2003).

### 7.1 Effects on Crustaceans

Compared to fish and marine birds, fewer studies have been done on crustaceans. Populations of lobster, shrimp and megrim declined the year after the Prestige spill, but were considered returned to normal the following year (Albaigés et al. 2006).

The Norwegian lobster (*Nephrops norvegicus*) was affected by the oil contamination after the *Braer* spill. In lobsters with residence in soft sediment burrows in a severely contaminated area, the concentration of PAH was the same as in the sediments, which was found to be elevated after the spill (Kingston 1997).

### 7.2 Effects on Bivalves

As mussels bioaccumulate contaminants through filter-feeding they are very suitable for monitoring pollutants in the marine environment and *Mytilus* spp. are frequently applied for this purpose (Laffon et al. 2006). The uses of DNA strand breaks as a biomarker to assess the presence of PAH pollutant is a well described method (Laffon et al. 2006).

After the *Prestige* spill the PAH levels in the mussels analyzed was elevated, but returned to background levels about 6 months after the spill (Albaigés et al. 2006). Bivalves accumulate most of the PAHs in the gonads and high lipid containing tissues, and after the *Braer* spill measurements showed 5-10 times higher concentrations than in muscular tissue (Kingston 1997). However, after one year levels returned to background level.

When measuring PAH levels in *Mytilus trossulus* 3-4 years after EVOS, Thomas et al (1999) found significantly higher levels in mussels that had been exposed to oil and were overlying oiled sediments, than in mussels from unexposed areas. However, when measuring physiological characteristics such as byssal threads, there was no difference. Further, this suggested that the mussels may have developed a tolerance to the oil exposure. The background level of PAH was suggested to account for the equality in physiological characteristics (Thomas et al. 1999).

When investigating responses to crude oil in arctic clams (*Chlamys islandica*) to crude oil, results showed impaired immune responses, cell membrane instability, reduction in phagocytosis and increased oxidative stress. Adaptations in arctic species include increased content of unsaturated fatty acids in the cell membrane that make them able to tolerate low temperatures. As cell membrane stability is affected by exposure to crude oil, this may in turn affect the organisms' survival in the arctic environment. The reduced immune response observed during the experiment did not recover after the exposure, indicating a lasting effect (Hannam et al. 2009). Other experiments on clams show that clams exposed to oil burry more slowly in the sand and hence are more at risk for predation (Teal & Howarth 1984).

### 7.3 Effects on Fish

Intensive studies have been done both on adult fish and fish larvae in relation to oil toxicity. Fish eggs and larvae are generally very sensitive to oil pollution (Dragsund et al. 2004). Whereas adult fish will have the possibility to avoid the oil contaminated areas, eggs or fish

larvae does not have this option and oil may be toxic to fish larvae at low concentrations (Teal & Howarth 1984).

Reynaud & Deschaux (2006) stated that fish are quite sensitive to especially the PAH components of oil, leading to several both specific and non-specific response by the immune system. The specific responses may involve the production of antibodies, and the unspecific responses may involve effects on increased activities such as lysozyme and/or phagocytosis. Responses may depend on PAH compound, concentration and route of exposure (Reynaud & Deschaux 2006).

The Pacific herring (*Clupea pallasii*) spawned in the area shortly after the EVOS accident had observable malformations such as reduced or absence of jaws or severe craniofacial malformations that can be related to toxic effects of oil exposure. The eggs of the herring are laid in subtidal kelp forests, and this makes them especially vulnerable to coastal oil spills (Norcross et al. 1996). This species inhabits high ecological value in the ecosystem as it serves as a food source for mammals, fish and marine birds. Reduced larval activity as a result of oil exposure was observed, and as a result of this failed to avoid predation. The Pacific herring was severely affected by the spill and population collapsed in 1993. It has not yet recovered (Norcross et al. 1996). Heinz et al. (1999) found sublethal effects in Herring eggs at very low concentrations of oil (0.4 ppb TPAH). Also, reports on an incident where herring eggs were found to have increased fungal disease as the gammarids that normally prevent this, died from the oil exposure (Nellbring et al. 1980).

Following the EVOS it was claimed that the oiled beaches caused salmon eggs to be damaged due to high concentrations of oil in the sediments. When investigating weathered *Exxon Valdez* oil exposures to pink salmon (*Oncorhynchus gorbuscha*) embryos, the research showed that the weathered oil did not reach high enough concentrations in the interstitial water that surrounded the eggs (Brannon et al. 2007). In an ecological point of view the impact on the population was not large enough to have effects on the population levels and the pink salmon is considered to be fully recovered after the spill (Harwell & Gentile 2006).

By measuring their respiratory function, Claireaux & Davoodi (2010) found that common soles (*Solea solea*) exposed to hydro carbons in the environment were to a lesser extent able to handle environmental changes than the unexposed control group. It was assumed that if respiratory function weakened as a response to temperature when exposed to oil, the fish would exhibit less ability to face environmental changes (e.g. temperature fluctuations) (Claireaux & Davoodi 2010).

When exposing Atlantic cod (*Gadus morhua*) to low concentrations of crude oil. In addition to a dose dependent response in bile metabolites, Cytochrome P450 and DNA adducts, responses was observed at very low concentrations (0,06ppm oil in water, PAH concentration 0,3ppb), which is one of the lowest concentrations responses has been detected. Concentrations of PAH in seawater 14 days after the EVOS was measured to 0.9 and 6.2 ppb. , suggesting that concentrations were high enough to have an effect in cod. Dose dependent responses may provide a powerful tool when assessing environmental risk, and biomarkers for reactive oxygen species, like Cytochrome P450 (Cyp1A), provide a powerful tool when assessing sublethal effects to fish, as the biomarkers may indicate more severe effects e.g. neoplasia to the liver (Aas et al. 2000).

## 7.4 Effects on Marine Mammals

### Sea Otters

The sea otter (*Enhydra lutris*) was heavily affected by the EVOS, and mortality was high after the spill. This was caused by damages to kidney, liver and lungs were reported after the accident (Monson et al. 2000). Their insulating coat protects against cold water and temperature, and disruption from oil may cause the same problems as in birds. Hence it's crucial that the insulating fur is functional. Long time effects also seem apparent as the species had a long recovery time, and one population in particular does not show signs of recovering 11 years after the accident. The lifecycle of the sea otter involves burrowing and foraging for mussels and clams in tidal and intertidal areas. This exposes the sea otter to lingering oil in the sediments as well as through intake of oil contaminated clams and mussels. Sea otters exposed to oil showed significantly higher levels of Cytochrome P450, CYP1A1, biomarker than unexposed otters (Bodkin et al. 2002). The sea otter is long lived and

has a low annual reproduction, which may serve to delay the recovery of the population (Bodkin et al. 2002).

After the *Server* spill Eurasian otters (*Lutra lutra*) were monitored to check for exposure, deaths and effects. A few observations of oiled otters were reported, however, if severely affected they will go into hiding before they die. This makes estimates on deceased otters very difficult (Lorentsen et al. 2008).

### **Seals**

After the EVOS it was reported that approx. 300 harbour seals (*Phoca vitulina*) died shortly after the accident. The seals were subjected to inhalation of the volatile part of the oil, and it is found likely that this in turn was the cause of death (Loughlin 1994). After the *Braer* grey seals were experiencing respiratory distress and nasal mucus discharge 30 days after the accident. This was unexpected as the acute effects after the EVOS was observed in a shorter period of time after the accident (Hall et al. 1996).

### **Whales**

Increased mortality in one pod of Killer whales (*Orcinus orca*) was observed after the EVOS, however scientists could not identify cause of death in these. As the killer whales are long lived animals with low reproductive rate the pod in question still had not recovered by 2006 (Harwell & Gentile 2006).

## **7.5 Effects on Marine Birds**

Birds are often extensively affected in an oil spill. Both acute and sublethal effects have been studied after spills. As they are on the upper level of the food chain, effects are anticipated to be observed in them as well as their predators (Alonso-Alvarez et al. 2007). However, there is little relationship between the amount of oil spilled and number of birds killed in an oil spill (Kingston 1997). This was evident in the case of a smaller spill in the Baltics in 1976. A tanker released a few tonnes of oil when using seawater to clean the tanks. The oil had a calming effect on the sea, attracting a flock of long-tailed- ducks (*Clangula hyemalis*), and as a consequence 60 000 individuals died due to oil exposure. This shows clearly that the

number of killed birds is not necessarily related to the amount of oil released (Jernelöv 2010). This example also demonstrates that at least some bird species do not seek to avoid the oil.

Increased adult mortality and reproductive effects were registered after the Prestige spill. Levels of hydrocarbon concentration in eggs were found elevated in Peregrine Falcon (*Falco peregrinus*) eggs after hatching. The Peregrine Falcon hunts prey in the air, usually not coming into contact with contaminated water. The high levels indicates high levels of hydrocarbon content in the diet of the nesting bird in the time prior to egg laying (Zuberogoitia et al. 2006). This shows evidence of further contamination to the chick and thus indirect effects of the spill that has the potential to affect the population level. Mortality rates increased the second winter after the spill, indicating sub- lethal effects.

When looking at the EVOS, diving taxa seemed to be affected harder than taxa of surface feeders (Irons et al. 2000), and shore line dependent taxa harder than offshore taxa (Lance et al. 2001). It is estimated that around 250 000 birds were killed by the effects of the oil from the Exxon Valdez (Piatt & Anderson 1996). The effects were observed on many populations of birds, many of which have been enrolled in research programmes after the accident. The most affected was the murre (Uria spp.). Even years after the accident we experienced lower breeding success and decrease in populations. Levels were back to normal about 4 years after the accident. However, when assessing populations it is difficult to attribute declines to any one factor as many of the bird populations had been declining before the EVOS (Piatt & Anderson 1996). When assessing impacts of oil spills many factors can influence the outcome. Lack of, or very scarce data from pre- spill conditions may provide a false picture of the situation (Albaigés et al. 2006).

Different life stages may have different sensitivity to oil e.g. moulting stages or reproduction faces. This is evident in the Appendix I (in Norwegian) that takes vulnerability into consideration at different seasons and different life stages (Alpha Miljørådgivning AS 2008).

Research has been done on yellow- legged gulls (*Larus michahellis*) in association with the *Prestige* oil spill in 2002. Alonzo- Alvarez and Pérez (2007) performed an experiment where a selection of breeding yellow- legged gulls were fed bread containing *Prestige* oil and vegetable oil, whereas the control group was fed bread with vegetable oil only. The plasma levels of the group that was fed the oil containing food showed reduced glucose levels and reduced inorganic Phosphorus (iP). This may suggest that the gulls had a lower food intake, but both body mass and hematocrit point to the fact that this is very unlikely. The total PAH present in the *Prestige* oil is believed to cause damage to the liver, and therefore disrupt the liver's role in the glycogenesis, leading to low levels of glucose (Alonso-Alvarez et al. 2007). The similar low iP values have been reported in pigeon guillemots (*Cephus columbia*) after the EVOS (Seiser et al. 2000).

Perez (2010) also investigated activation of antioxidants as a response to oxidative stress from oil exposure, in the same setup as mentioned in the previous section. Antioxidant systems are induced to counteract oxidative stress from oil exposure. The exposed group showed clear signs of oxidative stress. Higher blood levels in PAH and plasma concentration of vitamin E and carotenoids, both antioxidants, were higher in the exposed group. This indicated activation of antioxidants to reduce oxidative stress. Carotenoids was indicated to be associated with the size of the red spot on the beak of the gull, as the carotenoids are assumed to be important to the coloration and size of the spot. These spots are important during the mating process and in the feeding response of the chicken. The exposed gulls had higher carotenoids in plasma to counteracting oxidative stress as a response to PAH exposure, affecting the total carotenoids level in such a way that less carotenoids was available for the bill spot, reflected in a smaller sized spot (Pérez et al. 2010).

Cytochrome P4501A (CYP1A) has frequently been measured on Harlequin Ducks (*Histrionicus histrionicus*) after the EVOS. Inhabiting subtidal and intertidal zones, the harlequin duck is present in Prince William Sound year round exposing them to oil contamination of any effects of residual oil in the years following the spill. Elser et al. (2010) found significantly higher levels of CYP1A in ducks from areas exposed to oil. The results were the same for both male and female. Research on biomarkers was performed in 1998 and 2005 through 2009, 20 years after the EVOS (Esler et al. 2010).

Lance et al. (2001) investigated 29 populations of birds in the Prince William Sound, comparing population of oiled sites to population of unoiled sites. Of the 29 populations, 5 populations showed signs of increase, 8 populations exhibited a decrease and 16 showed no change. The effect of the 8 populations may be the result of lack of food, reduced carrying capacity of the area or lasting effects of the oil spill. Some of the populations, however, were exhibiting decreasing trends even before the accident. A still decreasing trend in these populations may be a continued effect of something other than the spill (Lance et al. 2001).

Estimates of the number of deceased birds after the MV Full City spill are estimated to be around 2500 individuals, and the most affected species was the common eider (*Somateria mollissima*). After the accident, there apparently was an increase in the eider population. This was probably because the hunt for eiders was called off in the year of the accident, leaving the saved eiders with a higher survival rate (Sletner et al. 2010).

The *Server* spill caused estimated 3000-8000 deaths in marine birds. The large affected area made an impact on several bird populations, and Herring gulls (*Larus argentatus*) and common eiders was considered to be the most affected. Also, an already reduced population of Black Guillemots was affected. The area where the ship stranded was a breeding and nesting area for Herring gulls, but follow up investigations in the summer of 2007, showed that the Herring gulls had not used the area. The Norwegian Institute for Nature Research (NINA) did not expect any long term negative effect in the bird population as the spill was merely considered a surplus negative effect to the existing pressure on bird populations. Oil spills impacting already threatened populations may serve to completely wipe the species out from one area (Byrkjeland et al. 2008).

## 7.6 Changes in communities and ecosystems

An oil spill is a source of stress to the environment that comes in addition to already existing impact from both anthropogenic and natural sources. The spill may cause habitats to change, making it less hospitable for the inhabiting species. Organisms that forage in the intertidal



zone, and are affected either directly by the oil, or indirectly by reduction in access to food from this zone, may have an indirect impact (Lance et al. 2001). Lingering oil in the environment may lead to chronic exposures that lead to delayed effect in ecosystem recovery (Peterson et al. 2003).

The loss of species of particular importance to the ecosystem may have structural effect on the ecosystem. These species are commonly referred to as keystone species. Keystone species may have a long life expectancy, making recovery of these species very slow. The keystone species may include among others species of mammals, birds and some species of snails, bivalves and crustaceans (Moore 2006).

Some species may be quite sensitive to the oil, and may experience severe acute effects as a result. Other species may be more tolerant, and may become more abundant. The Lugworm (*Arenicola sp.*) was present in large amounts after spills in soft sediment areas, indicating a higher tolerance for hydro carbons. Nematodes also seem to exhibit some tolerance, whereas *Ostracoda sp.* seem to be more sensitive (Gundlach et al. 1981). Less competition from sensitive species also favours the more oil tolerant organisms (Carrera-Martínez et al. 2010). When it comes to recolonization of a habitat following a spill, opportunistic tolerant species may be the first to return (Teal & Howarth 1984). Reestablishment of species that was severely affected or are sensitive to oil, may take longer than for more tolerant species (Teal & Howarth 1984).

“Ecological recovery is marked by the re-establishment of a biological community in which plants and animals characteristic of that community are present and functioning normally- this function being manifest primarily by normal levels of both biodiversity and productivity.” (Baker et al. 1990)

After the spill of *Braer*, even though the spill was much larger than the EVOS, the effects was considered to be minor and research showed no signs of mass mortality following the accident. This may be due to less toxicity of the spilled oil, or weaknesses in documentation

and timing of the research post accident (Kingston 1997). The oil type of the Braer spill was a light crude oil (Ritchie 1993), whereas the EVOS spill was heavier crude.

Zabala (in press) suggests that the effects from the *Prestige* on storm petrels returned to pre-spill conditions after 3 years (Zabala et al. 2010). The effects after the Jessica spill in the Galapagos Islands were also difficult to attribute to changes in the environment caused by the oil (Edgar et al. 2003). Difficulty in assessing and attributing effects to a specific cause may give a misleading impression of the situation and may indicate less or different impacts than expected.

The total impact a spill has on the ecosystem will always be difficult to predict due to the complexity of the system itself, along with all the other influencing factors regarding the spill itself and environmental factors. The figure illustrates how affected areas may be subjected to different exposures and that an holistic approach to ecosystem evaluation is needed (Lubchenco 2010).



Figure 3: Areas affected by the Deepwater Horizon spill, and different factors influencing the outcome of the accident (Lubchenco 2010).

## ***Chapter 8: Possible Scenarios in Norway- Jæren***

### **8.1 Scenario**

To describe which parameters are influencing an oil spill, this scenario has been constructed to provide a simplified view. Different parameters based on dividing seasons in two groups at time of accident; spring/ summer and autumn/ winter.

A cargo ship breaks ground and 300 tonnes of bunker oil leaks out into the marine environment. The affected area is on the coast of Rogaland, Jæren south of Stavanger (Figure 4). Wind and current leads the oil to shore. The scenario was chosen due to the fact that DNV report 3121048 (for the Norwegian Coastal Administration) concludes that the vulnerability to this area is high due to a high density of MOB A areas, as shown in Table 1 (Dragsund et al. 2004).

The area contains bare rock-face, rocky shores, sandy beaches, muddy beaches and coastal wetland area protected under the Ramsar convention (Ramsar 2010). The exposure to waves is variable, although most of the area is in direct exposure to the North Sea. The wetland area consists of tidal flats of fine particle muddy ground with little/no wave action. The area is used frequently by about 20 000 birds, and is important as a foraging, nesting and resting area, and is considered an important area for wintering (Fylkesmannen i Rogaland 2007).

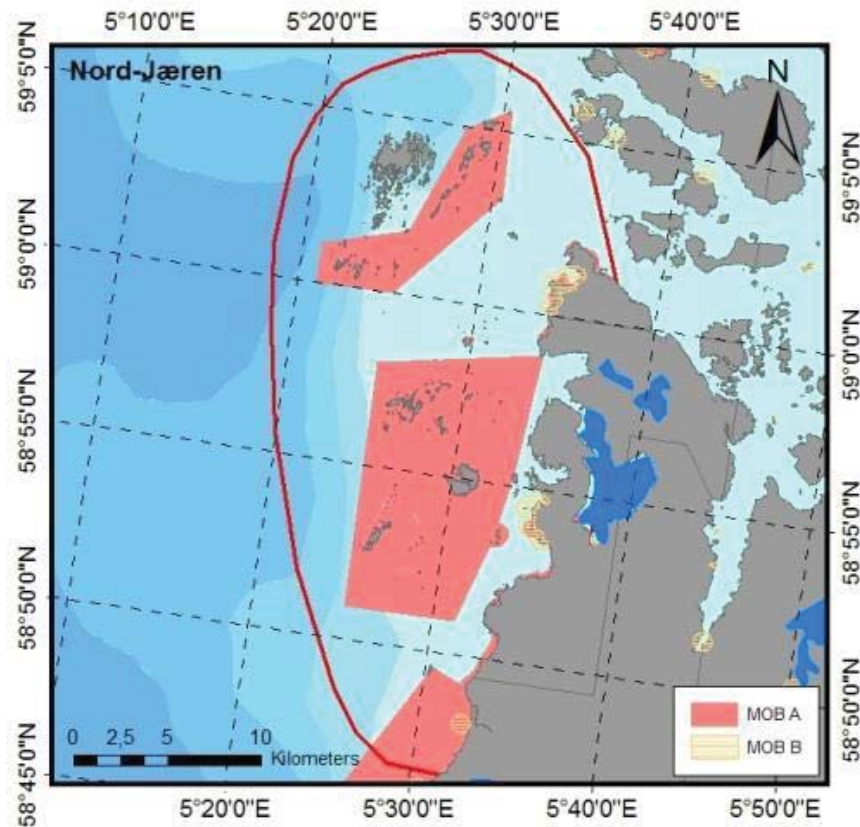


Figure 4: MOB area Nord Jæren for all seasons (NOFO 2008a)

### *General:*

Different types of beaches have a different vulnerability when it comes to oil spills. As previously mentioned oil will sorb to particles (Boyd et al. 2001). This means more oil sorbed to particles on sandy beaches and soft sediment wetlands. The oil will also seep further in to the soft sediments, and persist in this environment for a longer time than rocky shores as seen from the example of the EVOS. Also small pebbled beaches may be quite porous leaving room for oil seeping into the ground. Rocky shores will not have this problem to the same extent. The degree of wave and storm action and exposure to these will greatly affect how long the oil stays in the environment. Waves and storm action are important to “wash” the shoreline and further disperse stranded oil.

### *Spring & Summer*

The Table 1, showing count of MOB areas in different Counties, shows a higher amount of MOB A and MOB B areas than in the autumn/ winter, indicating a higher vulnerability to the area in the spring/ summer period.

The temperature in spring is low but increasing. Lower temperature will make the oil less water soluble and also less may evaporate. The fraction of oil evaporation is dependent on weather conditions. This is also dependent on oil type (Boyd et al. 2001). Natural dispersion of oil may be lower than winter/ autumn due to less wave action.

Higher density of organisms present in spring/ summer increases the risk for more extensive effects. Any presence of eggs and larvae of fish makes these exposed to smothering and oil components dissolved in the water as described previously. Oiling of areas of value to resting, foraging and nesting may put the birds at great risk for contamination. With presence of migrating birds preparing for breeding and nesting, the risk of affecting these is high. Exposure through smothering, ingestion and disruption of insulation is most acute. In addition oil pollution may be transferred to chick if parents are exposed through digestion.

Temperature is generally higher in summer, causing more of the oil to evaporate, and more of the water soluble components to dissolve in the water. The higher temperature will also affect the biodegradation, which will be higher than in other seasons. Higher UV radiation will cause higher rate of photo degradation. Wave action is normally less than in winter, resulting in lower physical dispersion. Higher production and all over activity makes total possible effects high. Birds would possibly be exposed through fowling and ingestion, and potentially contaminate chicks through fowling and feed. The total presence of wildlife and all over production is higher in the spring/ summer leaving a higher potential for severe acute effects.

### *Autumn & Winter*

As seen in Table 1, the autumn/ winter season contains less MOB A and MOB B areas than the same area for spring/ summer. The explanation for this may be that migrating birds may be present and use area for nesting and foraging in spring/ summer.

Temperature is lowest in the winter and slightly higher in the autumn. Low temperature affects evaporation rate, and less of the oil will evaporate than during the summer. The temperature also causes lower rate of biodegradation. Due to higher wave action and winter storms the natural dispersion of oil is allowed to work. However, waves and extremely high tides may cause the oil to reach higher up into the supratidal zone. Oiling in these areas may receive less wave action if tide goes down, and therefore oil may persist. Still, generally high exposure to the area will have a positive effect in regards to dispersing the spill.

Contamination before migration may put extra pressure on birds. In winter, migrating birds are not present so there will be no exposure to them. Wintering birds that are present will have added stress from oil pollution in both autumn and winter. The seasons have lower production along coastline and a general lower activity in the organisms present. If a spill happens during autumn/winter, a lack of food and temperature strain on organisms may have a negative effect in addition to already existing pressure.

However, in a total consideration of the impacts an oil spill may have during the different seasons, winter is probably the season that will have the least effect due to the least amount of organisms present and relatively low activity compared to e.g. summer.

The recovery of a spill is an ongoing situation, meaning that if a spill happens at summer, the oil will still be present the following autumn and winter. The parameters of the season will then work on the spill. However, organisms may be affected by oil persisting in the environment from a spill that happened prior in time, providing a source of chronic exposure and organisms may be prone to sublethal effects as discussed in the previous chapter.

## ***Chapter 9: Discussion***

The world's marine ecosystems are under constant pressure from natural changes and human impacts. Pollution from oil spills represents a threat to marine habitats, adding to already existing pressure on ecosystems. The oil does not only cause acute damages to the organisms, but might also cause sub-lethal effects due to long term low concentration exposure.

The effect on ecosystems will be influenced by oil type, spill size, season, temperature, wind, wave action and current. The composition of area and the substrate will also greatly influence how long the oil stays in the environment. Influences on the ecosystem are shown to vary greatly from spill to spill. The effects of the spill are not necessarily proportionate to the spill size, as was demonstrated in the Baltics where 60 000 ducks were killed by a very small spill.

When comparing The Braer spill and the EVOS, the smallest spill is not automatically the one that recovers the fastest. The *Braer* spill recovered fairly quickly as opposed to the EVOS that are still experiencing effects 21 yrs after, even though the *Braer* spill was close to double in spill size. This demonstrates that the spill size is not necessarily the largest influence on the damage of the spill. The difference in oil type was demonstrated in the *Braer* spill where the oil was a light crude oil, and the EVOS that was a heavier oil type (North Slope Alaska Crude oil). The difference in wave action and storm episodes between the spills probably played a significant role in dispersing the oil at the time of the accidents. This may play a very important role for recovery in colder climate areas in combination with oil type.

Organisms dependent on habitats in the intertidal zones and benthic organisms associated with the sediments are the ones most affected by spills. This includes otters, marine birds and mussels and clams, some of which may be keystone species of the ecosystem (Moore 2006).

The acute effects of oil spills include smothering, fouling of feathers or fur causing hypothermia, ingestion of toxic oil and respiratory problems. Long term exposure to lingering oil in the environment may lead to sublethal effects related to increased oxidative stress, reduced reproduction and increased mortality. The use of biomarkers in environmental



monitoring is increasing, providing better more secure methods for identification of sublethal effects.

The environment always contain more than one stressor, making it very difficult to attribute one effect to one stressor. The fact that the stressors may affect each other, in turn makes it even more difficult, making the need for accurate research methods in this area great. In addition sublethal effects from chronic exposure to oil may be very difficult to determine, as they may be masked by natural fluxes in the population and need accurate detection methods (Moore 2006).

Some species may be more sensitive to oil and disappear completely after a spill when another species may be more tolerant and become more abundant. This dynamic may be used when investigating species abundance after a spill. The abundance of oil tolerant species may indicate an effect/ change in the ecosystem, and monitoring species distributions may function as an important tool for measuring recovery.

Kingston (1997) argues that the effects seen after oil spills are mostly short-lived, and that the marine environment has a great capacity for recovery after spill events, a view that is also shared by Moore (2006). Organisms with a short life span, e.g. many intertidal species, have great adaptability and recover faster (Kingston 1997). However recovery is dependent on the circumstances in every situation. Heavy oils, little wave exposure and low temperatures in total will increase recovery time, as seen in the case of EVOS.

This thesis provides an overview of the oil spill situation and the effects on ecosystems. The risk of spills along the Norwegian coastline is predicted to increase in the following years, creating a greater risk for oil spills. The last part of the thesis investigates a scenario based situation of Jæren in Rogaland, Norway. This case seeks to emphasize the different factors that influence the outcome of the spill, in different seasons. After investigating the situation, I consider the spring/ summer scenario to have the highest possibility for extensive effects due to the higher density of organisms present at this time.



The Deepwater Horizon blow out put oil spills back on the agenda, as the biggest oil spill the world has ever seen, it points to the need for predictive tools and ecosystem understanding even more evident. Methods that provide better information on population, community and ecosystem impact are needed. There is a need for more research on several species, and sophisticated methods for early response biomarkers should be used. Spills provide a unique possibility to investigate effects in a situation involving all the dynamics present in the environment that cannot be recreated in laboratory. Research in responses in different species, populations, and in turn ecosystems are needed to better comprehend the collective pressure on the environment. This knowledge may facilitate better management and recovery of ecosystems that have been affected by a pollution event.

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# Appendix

## Appendix I

Informasjonen i dette vedlegget er hentet fra oljevernportalens nettsider:

<http://www.beredskapsportalen.no/contact/sorbarhetsperioder.htm> (Cited: 02.12.2010)

Denne siden presenterer tabeller over sårbarhetsperioder for gruppene fisk, sjøfugl, marine pattedyr, strand og naturbaserte aktiviteter og næringer. Utvalgene i listene av arter/ typer innen de ulike gruppene tilsvarer utvalgene i MOB (SFT & DN 1996).

Tabellene gir informasjon om de enkelte artene/ gruppene på månedsbasis der sårbarhetsperioder og sårbarhetsverdi er angitt i samme felt med henholdsvis bokstavkoder og fargekoder. Forklaringer på koder er gitt under de ulike grupperingene. Informasjonen i tabellene oppsummerer den informasjonen som ligger om sårbarhet og sårbarhetsperioder for den enkelte art/ gruppe på sidene Artsfakta og Biotopfakta. For dokumentasjon av kriterier benyttet ved tildeling av stadier og sårbarhetsverdi se kriterier for [MOB](#).

### Fisk

Tabellen viser sårbarhetsstadier/sårbarhetsverdier fordelt på måneder for ulike arter fisk.

**Forkortelser:** Egg og larver (E/L), Larver (L), Egg (E), Øvrige stadier (Ø).

**Forklaringer:** Sårbarhetsverdi 3 (rød/mørk), Sårbarhetsverdi 2 (orange/lysere), sårbarhetsverdi 1 (gul/lys). Hvitt felt med tekst angir måneder med sårbarhetsverdi 0, mens hvitt felt med (-) viser måneder der det ikke er satt sårbarhetsperiode eller sårbarhetsverdi.

**Referanser:** Hopkins & Nilssen (1991), Moe et al. (1993), SFT & DN (1996).

Norsk navn	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des
Lodde	Ø	E	E	E	E/L	E/L	L	Ø	Ø	Ø	Ø	Ø
Sei	Ø	E/L	E/L	E/L	L	Ø	Ø	Ø	Ø	Ø	Ø	Ø
Sild	L	E/L	E/L	E/L	L	Ø	Ø	E	E/L	L	L	L
Torsk	E	E/L	E/L	E/L	E/L	L	Ø	Ø	Ø	Ø	Ø	Ø

## Sjøfugl

Tabellen viser sårbarhetsstadier/sårbarhetsverdier fordelt på måneder for ulike sjøfuglarter.

**Forkortelser:** Hekking (H), Næringssøk (N), Hvile (Hv), Myting (M)

**Forklaringer:** Sårbarhetsverdi 3 (rød/mørk), Sårbarhetsverdi 2 (orange/lysere), sårbarhetsverdi 1 (gul/lys). Hvitt felt med tekst angir måneder med sårbarhetsverdi 0, mens hvitt felt med (-) viser måneder der det ikke er satt sårbarhetsperiode eller sårbarhetsverdi.

**Referanser:** Anker-Nilssen et al. (1988a), Lorentsen et al. (1993), SFT & DN (1996).

Norsk navn	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des
Alke	V	V	V	H	H	H	H/M	M	M	V	V	V
Alkekonge	V	V	V	V	H	H	H	H/V	M	M/V	V	V
Bergand	V	V	V	V	V	-	-	-	V	V	V	V
Fiskemåke	V	V	V	V	V/H	H	H	H/V	V	V	V	V
Fjelljo	-	-	-	V	V/N/Hv	N/Hv	N/Hv	V	V	V	-	-
Fjæreplytt	V	V	V	V	H	H	H	V	V	V	V	V
Gravand	-	-	V	V	H	H	H/M	M	M/V	V	-	-
Grønlandsmåke	V	V	V	V	-	-	-	-	V	V	V	V
Grågås	-	V	V	V/H	V/H	H/M	H/M	M	M/V	M/V	V	-
Gråhegre	V	V	V	H	H	H	H	H	V	V	V	V
Grålire	-	-	-	-	-	-	-	V	V	V	V	V
Gråmåke	V	V	V	V/H	H	H	H	H/V	V	V	V	V
Gråstrupedykker	V	V	V	V	V	-	-	V	V	V	V	V
Gulneblom	V	M	M	M	V	V/N/Hv	N/Hv	N/Hv	N/Hv	V	V	V
Havelle	V	V	V	V	V/H	H	H	M	M/V	V	V	V
Havhest	V	V	H/V	H/V	H/V	H/V	H/V	H/V	V	V	V	V
Havlire	-	-	-	-	-	V	V	V	V	V	V	V
Havsule	V	V	V	H/V	H/V	H/V	H/V	H/V	V	V	V	V
Havsvale	-	-	-	-	-	-	V	V/H	H	H	H	H
Havørn	V	V	H	H	H	H	H	V	V	V	V	V
Hettemåke	V	V	V	V/H	H	H	H/V	H/V	V	V	V	V
Horndykker	V	V	V	V	V	V	-	V	V	V	V	V
Hvitkinngås	-	-	-	-	V	V/H	H	H/M	M	V	V	-
Islom	V	M	M	M	V	V/H	H	H	H	V	V	V
Ismåke	V	V	V	V	H	H	H	V	V	V	V	V
Kanadagås	V	V	V	H	H	H	H	V	V	V	V	V
Knoppsvane	V	V	V	V/H	H	H/M	M	M	V	V	V	V
Kortnebbgås	-	-	-	-	V	V/H	H	H/M	M	V	V	-
Krikkand	V	V	V	V	H	H	H	H	V	V	V	V
Krykkje	V	V	V	V/H	H/V	H/V	H/V	V	V	V	V	V
Kvinand	V	V	V	V	V	-	-	-	V	V	V	V
Laksand	-	-	-	V	V	-	M	M	M	V	-	-

Lomvi	V	V	V	H	H	H	H/M	M	M	V	V	V
Lunde	M/V	M/V	V	H	H	H	H	H/V	V	V	V	V
Makrellterne	-	-	-	V	V/H	H	H/V	H/V	V	-	-	-
Polarjo	-	-	-	V	V	V/N/Hv	N/Hv	N/Hv	V	V	V	-
Polarlomvi	V	V	V	H	H	H	H	H/M	M	M/V	V	V
Polarmåke	V	V	V	V	H	H	H	H	V	V	V	V
Polarsvømmesnipe	-	-	-	-	V	V	H	H	V	-	-	-
Praktærfugl	V	V	V	V	N/Hv/V/H	N/Hv/H	N/Hv/M/H	M	M	V	V	V
Ringgås	-	-	-	-	V	V/H	H	H/M	M	V	-	-
Rødnebbterne	-	-	-	-	V/H	V/H	H/V	H/V	V	-	-	-
Sangsvane	V	V	V	V	V	-	-	-	V	V	V	V
Siland	V	V	V	V	V/H	H	H/M	M	M	V	V	V
Sildemåke	-	-	V	V	V/H	H	H	H/V	V	V	V	-
Sjørørre	V	V	V	V	V	V	-	-	V	V	V	V
Smålom	V	V	V	V	V/H	H	H	H/V	H/V/M	M	M/V	V
Steinvender	V	V	V	V	H	H	H	V	V	V	V	V
Stellerand	V	V	V	V	V/N/Hv	N/Hv	N/Hv	M	M	V	V	V
Stokkand	V	V	V	V/H	H	H	H/M	M	V	V	V	V
Storjo	-	-	V	V	V	H	H	H	V	V	V	-
Storlom	V	V	V	V	V	V	-	-	V	V/M	V/M	V/M
Stormsval	-	-	-	-	-	-	V	V	V	V	V	V
Storskarv	V	V	V	V/H	H/N/Hv	H/N/Hv	H/N/Hv	H/N/Hv	V	V	V	V
Svartand	V	V	V	V	V	-	-	-	V	V	V	V
Svartbak	V	V	V	H/V	H	H	H	H/V	V	V	V	V
Svømmesnipe	-	-	-	-	V	V	H	H	V	-	-	-
Teist	V	V	V	V/H	H	H	H	M	M/V	V	V	V
Tjeld	V	V	V	V	H	H	H/V	V	V	V	V	V
Toppand	V	V	V	V	V	-	-	-	V	V	V	V
Toppdykker	V	V	V	V	-	-	-	V	V	V	V	V
Toppskarv	V	V	V	V/H	H	H	H	H/V	V	V	V	V
Tyvjo	-	-	-	V	V/H	H	H	H/V	V	V	V	-
Ærfugl	V	V	V	V/H	H/V	H	H/M	M	M/V	V	V	V

## Marine pattedyr

Tabellen viser sårbarhetsstadier/sårbarhetsverdier fordelt på måneder for ulike arter marine pattedyr.

Forkortelser: Kaste/yngeområder (KY), Næringsområder (N), Hvileområder (Hv), Hårfellingsområder (Hå)

Forklaringer: Sårbarhetsverdi 3 (rød/mørk), Sårbarhetsverdi 2 (orange/lysere), sårbarhetsverdi 1 (gul/lys). Hvitt felt med tekst angir måneder med sårbarhetsverdi 0, mens hvitt felt med (-) viser måneder der det ikke er satt sårbarhetsperiode eller sårbarhetsverdi.

Referanser: Belikov et al. (1998a), Belikov et al. (1998b), Bjørge et al. (1995), Born et al. (1995), Christensen (1982), Gulliksen (1982), Haug & Nilssen (1994), Heggeberget et al. (1992), SFT & DN (1996), Wiig (1996).

Norsk navn	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des
Grønlandssel	N	KY	KY	Hå	Hå	N	N	N	N	N	N	N
Havert	N	Hå	Hå	N	N	N	N	N	KY	KY	KY	KY
Hvalross	N	N	N	KY	KY	(KY)	Hå	Hå	N	N	N	N
Isbjørn	N	N	N	N/Y	Y/N	N	N	N	N	N	N	KY
Nise	N	N	N	N	N/Y	N/Y	N/Y	N/Y	N	N	N	N
Oter	N/Y	N/Y	N/Y	N/Y	N/Y	N/Y	N/Y	N/Y	N/Y	N/Y	N/Y	N/Y
Ringsel	N	N	KY	KY	N	N	N	N	N	N	N	N
Spekkhogger	N(Y)	N	N	N	N	N	N	N	N(Y)	N(Y)	N(Y)	N(Y)
Steinkobbe	N	N	N	N	N	KY	KY/Hå	Hå	N	N	N	N
Storkobbe	N	N	(KY)	KY	KY	N	N	N	N	N	N	-
Vågehval	-	-	N	N	N	N	N	N	N	-	-	-

## Strandhabitater

Tabellen viser sårbarhetsstadier/sårbarhetsverdier fordelt på måneder for ulike strandtyper og strandressurser.

Forkortelser: Eksponert (E), Beskyttet (B)

Forklaringer: Sårbarhetsverdi 3 (rød/mørk), Sårbarhetsverdi 2 (orange/lysere), sårbarhetsverdi 1 (gul/lys). Hvitt felt med tekst angir måneder med sårbarhetsverdi 0, mens hvitt felt med (-) viser måneder der det ikke er satt sårbarhetsperiode eller sårbarhetsverdi.

Referanser: SFT & DN (1996).

Norsk navn	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des
Blokkstrand, beskyttet	B	B	B	B	B	B	B	B	B	B	B	B
Blokkstrand, eksponert	E	E	E	E	E	E	E	E	E	E	E	E
Elvemunning, beskyttet	B	B	B	B	B	B	B	B	B	B	B	B
Elvemunning, eksponert	E	E	E	E	E	E	E	E	E	E	E	E
Klippestrand, beskyttet	B	B	B	B	B	B	B	B	B	B	B	B
Klippestrand, eksponert	E	E	E	E	E	E	E	E	E	E	E	E

Leirstrand, beskyttet	B	B	B	B	B	B	B	B	B	B	B	B
Leirstrand, eksponert	E	E	E	E	E	E	E	E	E	E	E	E
Sandstrand, beskyttet	B	B	B	B	B	B	B	B	B	B	B	B
Sandstrand, eksponert	E	E	E	E	E	E	E	E	E	E	E	E
Steinstrand, beskyttet	B	B	B	B	B	B	B	B	B	B	B	B
Steinstrand, eksponert	E	E	E	E	E	E	E	E	E	E	E	E
Strandeng , eksponert	E	E	E	E	E	E	E	E	E	E	E	E
Strandeng, beskyttet	B	B	B	B	B	B	B	B	B	B	B	B
Svaberg, beskyttet	B	B	B	B	B	B	B	B	B	B	B	B
Svaberg, eksponert	E	E	E	E	E	E	E	E	E	E	E	E
Tidevannsdam / lagune, beskyttet	B	B	B	B	B	B	B	B	B	B	B	B
Tidevannsdam / lagune, eksponert	E	E	E	E	E	E	E	E	E	E	E	E

## Aktiviteter og næringer

Tabellen viser sårbarhetsstadier/sårbarhetsverdier fordelt på måneder for ulike sjøfuglarter.

Forklaringer: Sårbarhetsverdi 3 (rød/mørk), Sårbarhetsverdi 2 (orange/lysere), sårbarhetsverdi 1 (gul/lys), sårbarhetsverdi 0 (hvit).

Norsk navn	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des
Havneanlegg	-	-	-	-	-	-	-	-	-	-	-	-
Husdyrbeite	-	-	-	-	-	-	-	-	-	-	-	-
Industrifiske	-	-	-	-	-	-	-	-	-	-	-	-
Kystfiske	-	-	-	-	-	-	-	-	-	-	-	-
Låsettingsplasser	-	-	-	-	-	-	-	-	-	-	-	-
Marine oppdrettsanlegg	-	-	-	-	-	-	-	-	-	-	-	-
Mottaks-/prosesseringsanlegg	-	-	-	-	-	-	-	-	-	-	-	-
Nærområder til boligbebyggelse	-	-	-	-	-	-	-	-	-	-	-	-
Nærområder til fritidseiendommer	-	-	-	-	-	-	-	-	-	-	-	-
Nærområder til overnattingsforetak	-	-	-	-	-	-	-	-	-	-	-	-
Offentlige badeplasser	-	-	-	-	-	-	-	-	-	-	-	-

Offentlige turområder	-	-	-	-	-	-	-	-	-	-	-	-
Områder for guidet turisme	-	-	-	-	-	-	-	-	-	-	-	-
Settefiskanlegg	-	-	-	-	-	-	-	-	-	-	-	-
Taretråling	-	-	-	-	-	-	-	-	-	-	-	-

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