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Abstract

The former disputed area between Norway and Russia in the Barents Sea is of increasing interest when it comes to oil and gas exploration and production. The area is likely to open for exploration in the near future as the maritime delimitation and cooperation agreement between Norway and Russia concerning the Barents Sea were ratified by the Russian State Duma and signed by Russian President Dmitri Medvedev during the spring of 2011.

The impact of a blowout of oil with a long duration in this area is not well studied, and this thesis strives to describe some of the consequences associated with such an accident. A location was chosen in the disputed area and blowout scenarios were created to give data input to this case study. The location is at 73°N 32.30°E, and the distance from shore is approximately 258 km. A blowout of the order of magnitude as the blowout from the Macondo-prospect in the Gulf of Mexico was an initial point for defining the scenarios.

Oil drift has been modelled with OS3D for both weighted scenarios during all four seasons and long-term scenarios of 35 and 100 days. Results from the modelling have been compared to the presence of valued ecosystem components to suggest species and areas that are prone to harm.

Results from the oil drift modelling indicate that it is highly unlikely for oil released from this location to hit the shorelines of Norway and Russia, even during scenarios with long duration. This decreases the risk that the oil and gas activity on this location will pose to the environment, as vulnerable areas along the coast of Norway and Russia are left unaffected by the oil on the open ocean. Fish and marine mammals are prone to loss on an individual level, while pelagic seabirds are suggested to be the most vulnerable component due to its presence at the open ocean and the long restitution time of the populations.

Acknowledgements

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I would like to thank ENI Norge for permission to use oil data from the Goliat development, and Det Norske Veritas for permission to use specific data concerning the Norvarg prospect to broaden my understanding of well risk and the connection between well risk and environmental risk, both for the purpose of achieving sufficient background knowledge before establishing appropriate oil spill scenarios.

Last but not least I would like to thank family and friends for being supportive and for encouraging me throughout my education and lately throughout the work with this thesis. A sincere thanks also goes out to the employees of DNV Stavanger whom have all made me feel welcome and included me as a part of their organisation during my stay there.

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Abbreviations and definitions

LNG - Liquified Natural Gas

ALARP - As Low As Reasonable Practicable

MIRA - Miljørettet Risikoanalyse (Environmental risk analysis)

VEC - Valued Ecosystem Component

DNV - Det Norske Veritas

KLIF - Klima of forurensningsdirektoratet (Climate and Pollution Agency)

MRDB - Marine Resource Database

SEAPOP - Seabird populations monitoring and mapping programme

NINA - Norsk Institutt for Naturforskning (The Norwegian Institute for Nature Research)

SMO - Spesielt Miljøfølsomt Område (particularly vulnerable area)

OS3D - Derived from OSCAR model, indicating a 3D modelling

OSCAR - Model used for modelling of marine oil spills

SINTEF - Organisation for technical and industrial research

Sm^3 - Standard cubic metre

MSm^3 - Million Sm^3

GSm^3 - (derived from giga) Billion Sm^3

GOR - The ratio of produced gas to produced oil (gas/oil ratio)

BOP - Blowout Preventer

ROV - Remotely Operated Vehicle

BP - British Petroleum

BOEMRE - Bureau of Ocean Energy Management, Regulation and Enforcement (former MMS - Minerals Management Service)

IBA - Important Bird Areas (appointed by BirdLife International)

NOFO - Norsk Oljevernforening For Operatørselskap (Norwegian Clean Seas Association for Operating Companies)

ERA - Environmental Risk Analysis

1. Introduction

1.1. Objective

This objective of this thesis is to:

- Enlighten the environmental consequences associated with a blowout of oil in the former disputed area between Norway and Russia in the Barents Sea.
- Discuss the probability for having an accident in the Barents Sea that can be compared in terms of magnitude to the Macondo accident in the Gulf of Mexico during spring and summer of 2010.
- Assess whether tools and models used for analysing environmental risk on the Norwegian continental shelf are sufficient to enlighten the risk realistically.

1.2. Background

During the last decade the oil and gas industry have shown an increasing interest in the relatively unexplored areas in the north. In Norway, the northern part of the Norwegian Sea and the southern part of the Barents Sea have been the subject of most interest. Statoil was in 2002 given the permission by the Norwegian government to develop the Snøhvit gas field, and in 2007 the first gas was transported from the subsea facilities offshore to the LNG processing plant onshore [1]. The Snøhvit field was the first offshore development in the Barents Sea, and was the subject of a large debate between the oil and gas companies, the government and environmental organisations.

In the fall of 2000, Norwegian Agip (now ENI Norway) made a discovery of oil southeast of the Snøhvit field. This field was named Goliat and will, when production starts in 2014, be the first oil producing field in the Barents Sea [2]. On the Russian side of the maritime delimitation line, the most promising discovery is the Shtokman field. The Shtokman field was discovered in 1988 and is one of the world's largest natural gas fields. The field has so far not yet been developed. Gazprom, Total and Statoil is involved in the project, and production is estimated to start in 2016/2017 at the earliest.

In 2007, a treaty between Norway and Russia concerning maritime delimitation and cooperation in the Barents Sea and the Arctic Ocean was established. This ended a 40-year-old dispute about who has the rights to make use of the resources in the area. As this agreement is established, it is natural to assume that the oil and gas industry will increase their activity towards this area from both sides of the line. This area is henceforth called the disputed area. Statoil estimated in 2004 that the disputed area might contain as much as 12 billion barrels of oil equivalents (o.e.) [3]. During the spring of 2011, when the project on writing this thesis was in its final stages, the treaty between the two countries concerning maritime delimitation and cooperation was ratified by the Russian State Duma and later signed by Russia's President Dmitri Medvedev, making it law in Russia and opening the possibility for exploratory drilling in the new area.

As the oil and gas industry moves north eastwards, offshore developments become more challenging. The climatic conditions get more extreme and the distance from infrastructure increases. This might increase the time needed for drilling a relief well and affect the duration of a blowout.

This thesis will discuss the environmental risk and environmental consequences associated with a blowout of oil in the former disputed area between Norway and Russia in the Barents Sea. It is also drawn parallels to the blowout from the Macondo formation in the Gulf of Mexico in 2010.

1.3. Limitations

This evaluation of environmental risk in the disputed area between Norway and Russia in the Barents Sea is the result of one mans work from January to June. Due to this fact, several simplifications have been done in order for the work to better suit the time and manpower limitations. An actual environmental risk assessment would require both more time and more people in order to achieve a satisfactory result.

This thesis considers consequences resulting from a blowout of oil, but avoids discussing whether it is probable that the blowout occurs in the first place. This is a deliberate choice made due to the time restrictions.

Information on the extent of valued ecosystem components in this thesis is based solely on Norwegian data. Data from Russian studies are excluded in order to simplify and due to time limitations.

It is chosen to exclude environmental impact on benthos. This is because the damage on benthos is assumed to be limited to individuals rather than populations. In addition, damage on species living in other compartments than the seabed is assumed to contribute more to the overall environmental risk and it is thus chosen to focus on these in this thesis.

1.4. Structure of thesis

The section prior to chapter 1 includes an abstract of the thesis, acknowledgements, a table of contents, lists of figures and tables and abbreviations and definitions used throughout the thesis.

Chapter 1 is an introduction to the thesis, including the objective, the background, the limitations and the structure of the thesis. Chapter 2 includes a theoretical background that gives the reader the basic knowledge about the subjects addressed in the thesis. This includes theoretical background knowledge on environmental risk and environmental risk analysis, modelling of oil spills, petroleum activity in the Barents Sea, the Macondo blowout in the Gulf of Mexico in 2010, weathering of oil in the marine environment and environmental resource databases.

Chapter 3 includes a description of the case study used in this thesis and a description of the input used for oil drift modelling in this thesis. Chapter 4 includes a description of natural resources and environmental characteristics of the area of interest to this thesis.

Chapter 5 presents the results from the oil drift modelling, chapter 6 includes a discussion of the results and chapter 7 presents the conclusions that can be drawn after assessing the results of the work with this thesis.

2. Theoretical background

2.1. Risk

Risk is a measure of potential loss that occurs due to natural or human activities [4]. It is desirable to completely remove risk. However, this is not possible, and there will always be risk connected to activities. In risk management, the term ALARP (As Low As Reasonable Practicable) is often used to evaluate to what extent the risk present is acceptable [5].

Risk can be defined as ”a term which combines the chance that a specified hazardous event will occur and the severity of the consequences of the event” [6]. Risk can be calculated by multiplying probability for an accident with a value for the consequence [7]:

$$R = \Sigma (p_i \times C_i)$$

Where:

p = Probability of accident

C = Expected consequence of accident

R = Risk

Risk analysis can be defined as ”an analysis that includes systematic identification and description of risk to personnel, environment and assets” [8]. Risk assessment can be defined as ”the entire process of analysing risk and evaluating results against the risk acceptance criteria” [7].

2.2. Environmental risk

Environmental risk is the risk an activity poses to the environment. The environment can be defined as all living and non-living elements occurring naturally on Earth. Environmental risk assessment is the process where environmental risks are identified and compared to the environmental risk acceptance criteria.

"The Norwegian Forum for Collaboration on Risk" assigns the term risk, with regard to their activities, to account for the two elements [9]:

- Potential causes for acute environmental pollution with subsequent uncertainty.
- Potential effects that have a negative impact on the ecosystems structure, function or productivity as a result of acute environmental pollution, with subsequent uncertainty.

This approach to the term risk is relevant for this thesis and will be used throughout the paper when discussing risk if not otherwise highlighted.

An environmental risk analysis is a methodical process where information about a number of environmental factors are obtained and systemized in order to carry out a qualitative or quantitative analysis. The following factors are essential to obtain in order to carry out an analysis [5]:

- Environmental risk acceptance criteria
- Location of oil spill
- Oil spill characterization
- Oil composition
- Wind and current data
- Existence of biological resources in the area of influence
- Value of resources
- Vulnerability of resources

In this case, the term value expresses the importance of resources. The importance of resources is based on scientific worth and/or red list status rather than fiscal value. Vulnerability can be defined as a species or element of an ecosystems ability to maintain its natural condition if affected by external (anthropogenic) stress. Vulnerability of an area is often based on the abundance of species and natural elements and the species ability to reproduce. Vulnerability can have seasonal variations, such as the spawning period for fish and the breeding period for seabirds.

There are several purposes with carrying out an environmental risk analysis [5]:

- Comply with governmental regulations
- Evaluate if the company's acceptance criteria and environmental goals are achieved
- Manage and reduce environmental risk
- Decision support
- Present documentation on environmental risk to environmental authorities and other public authorities
- Form a basis for choosing risk reducing measures, e.g. dimension oil spill response

This thesis considers unplanned environmental pollution, which according to paragraph 38 of The Pollution Control Act is defined as "significant pollution that occurs suddenly and that is not permitted in accordance with provisions set out in or issued pursuant to this Act" [10].

2.3. Method for environmental risk analysis (MIRA)

This section is based almost exclusively on the Norwegian Oil Industry Association's guideline for environmental risk analysis (MIRA) [5].

Method for environmental risk analysis (MIRA, for the Norwegian "Metode for Miljørettet Risikonalyse") is the Norwegian framework for carrying out environmental risk analysis. This framework was established in order for risk analyses carried out for operations on the Norwegian continental shelf to be comparable independent on what operator or contractor carried out the analysis. This promotes a clearer communication between the operators and the interested parties, and acts as a helpful tool when assigned to carry out environmental risk analysis.

2.3.1. Level of details

The MIRA accounts for three different types of analysis: the reference-based analysis, the exposure-based analysis and the damage-based analysis. The difference between the three types of analysis is the level of detail in both input and output from the analysis.

The reference-based analysis is the one that requires the least amount of input data. This analysis is only able to give a brief overview over the environmental risk level based on the low amount of input data. As the name of the analysis suggests, this analysis requires a reference analysis for comparison. A reference analysis can be an environmental risk analysis with subsequent oil drift simulations that is already carried out for a similar field in terms of both geography and geology. Using an oil drift simulation already carried out in close proximity to the area of interest reduces both time and costs on the new (reference-based) analysis.

The exposure-based analysis requires new oil drift simulations to be carried out specifically for the area of interest. This analysis compares the probability of oil impact with the presence of vulnerable and valuable resources. The risk estimated in this analysis accounts for the probability that a vulnerable resource within the area of impact is exposed to damage. The exposure-based analysis is more extensive than the reference-based analysis.

The damage-based analysis is the most extensive of the three. This analysis estimates the level of damage on selected resources and estimates the time it takes for the impacted resources to restore to its original state. The impacted resources are known as VEC's (Valued Ecosystem Components) and are chosen based on their value and vulnerability.

The risk acceptance criteria are defined at the beginning of an analysis, and do not depend on the extent of the analysis. The following table gives an overview over the data needed in order to carry out an environmental risk analysis according to the framework established by the Norwegian Oil Industry Association.

Table 2.1*: Input to MIRA. Ref. table 3-1 from [5].*

Input data	**Reference-based**	**Exposure-based**	**Damage-based**	**Source of information**
Probability of oil spill	✖	✖	✖	Databases at SINTEF, DNV, Scandpower, operators
Rate/duration distribution	✖	✖	✖	
Type of oil	✖	✖	✖	SINTEF's Oil Weathering Model
Particularly vulnerable areas (SMO)	✖	✖		KLIF - the Norwegian Climate and Pollution Agency
Oil drift simulation		✖	✖	Oil drift models
Valuable and vulnerable environmental resources		✖		MRDB, NATURBASE, SEAPOP
VEC's			✖	MRDB, SMO, research and studies
VEC -distribution			✖	MRDB, SMO, SEAPOP, research and studies
VEC - presence			✖	Research and studies

2.3.2. MIRA procedure

The MIRA is carried out according to the following steps [5]:

Step 1 : Define risk acceptance criteria

Step 2 : Establish activity description

Step 3 : Establish probability estimate for undesirable events

Step 4 : Establish a sufficient number of probable combinations of discharge rates and durations

Step 5 : Oil drift simulations

Step 6 : Damage estimations

Step 7 : Estimate environmental risk

The steps 1 to 4 are carried out regardless of type of analysis. The first step of the MIRA is to define risk acceptance criteria. The operator of the activity defines these risk acceptance criteria based on company environmental policy and goals. The risk acceptance criteria have several purposes. They should among other things comply with regulations given by the authorities, be established in an early phase of the project and contribute to the decision-making process regarding risk and risk reduction. In step 2, after the risk acceptance criteria are established, the operator defines the activity that is to be carried out and establishes an activity description. The activity description should include what kind of activity is carried out, the scope of the activity, information about the reservoir, information about previous analysis that might be used for comparison and other assumptions and considerations.

Step 3 consists of establishing a probability estimate for an undesirable event. This is normally based on the technical risk analysis carried out for the same operation. At step 4, a number of rates and durations that can occur given an undesirable event is listed and combined with their respective probabilities. The most probable undesirable events and the consequent rates and durations can often be established based on technical risk analysis carried out prior to the environmental risk analysis. And in general risk analysis spirit, if any simplifications are made they should contribute to a more conservative risk picture.

Step 5 is oil drift simulation and is only applied for exposure-based and damage-based analysis. For a reference-based analysis an existing oil drift simulation is found representative for the new activity. The oil drift simulation provides a basis for damage calculations and gives valuable information for the oil spill response planning. A number of input data have to be established before running the oil drift model. These data includes the rate and duration distributions that were established in step 4. Type of oil and the properties of the oil also have to be established before running the models.

Step 6 involves conducting damage calculations. These calculations vary between the three types of analysis. While the reference-based analysis compares the impact on the environment based on a more extensive analysis carried out in the past, the exposure-based and damage-based analysis calculates probability for oil impact on vulnerable resources and damage to VECs respectively. In step 7 the environmental risk is estimated based on the previous steps.

2.4. Modelling tool [11]

2.4.1. Oil drift modelling

In order to model the oil spill that constitute the foundation of this thesis, the OS3D oil drift model is used. OS3D is developed based on SINTEF´s OSCAR (Oil Spill Contingency And Response) model. The work on improving OS3D and adjusting it to represent an oil spill in the best possible way is carried out continuously by SINTEF and DNV. After the blowout from the Macondo prospect in the Gulf of Mexico in 2010 the latest version of the model was validated by SINTEF against the oil drift from said blowout.

2.4.1.1. OS3D

OS3D is a 3-dimensional oil drift model based on SINTEF´s OSCAR model. OS3D estimates amount of oil on the sea surface, on shorelines and sea bottom and concentration of oil in the water column. Both discharges from topside facilities and from the sea bottom can be modelled in OS3D. When modelling an oil discharge from the sea bottom, a separate module in OS3D is used. This module accounts for the fate of the oil from it is released at the sea bottom until it reaches the sea surface. Dilution of the oil and the time it takes for the plume of reservoir fluids to reach the sea surface is also estimated when a discharge from the sea bottom is modelled.

Output from OS3D is given in three physical dimensions (x,y,z) and time (t). The model includes databases for oil types, water depths, sediment types, ecological habitats and types of coastal zones. Spreading, transportation of oil sheets, mixing of oil down in the water column, evaporation, emulsion and beaching of oil is also included in the model in order to accurately estimate oil drift and fate on the surface. In the water column, horizontal and vertical transport, dispersion, adsorption and settling of oil in sediments and degradation is a part of the models calculations.

OS3D is able to carry out both single simulations for given wind- and wave patterns and stochastic simulations for different starting points of a blowout. It is essential that the discharge of oil that is modelled is modelled a sufficient number of cases in order to account for normal variability in metrological and oceanographic patterns. The statistical reliability is accounted for by running 3600 simulations for one scenario.

2.5. Petroleum activity in the Barents Sea

This part of the theoretical background is to a great extent based upon *"Det faglige grunnlaget for oppdateringen av forvaltningsplanen for Barentshavet og havområdene utenfor Lofoten"*, ref. [12].

The first exploration well in the Norwegian part of the Barents Sea was drilled in 1980 [12], and the first discovery of petroleum resources was made in 1981. This discovery is now a part of the Snøhvit development. The Snøhvit development was the first development in the Norwegian part of the Barents Sea. It was approved for development by the government in 2002, and the first gas reached the onshore LNG facility in August 2007. Snøhvit is a gas and condensate field, and is developed with subsea installations connected with pipeline to the onshore terminal (no facilities are located on the sea surface offshore).

Table 2.2: *Number of exploratory wells drilled in the Barents Sea* [12]

Year	1980-1990	1990-2000	2000-2010
Exploration wells drilled	43	10	27

As the table above suggests, there have been some fluctuations in the drilling activity in the Barents Sea. After the first well was drilled in 1980 the activity was relatively high the following decade. During the 1990s the activity decreased. In order to reverse the decreasing trend, the government initiated activity in the area by improving exploration conditions. The governmental initiative, in addition to the positive developments Snøhvit and Goliat, led to an increased activity during the 2000s.

Goliat is the first oil field in the Norwegian part of the Barents Sea, and was approved for development in 2009. The field consists of 27,5 MSm3 oil and 3,1 GSm3 gas that will be produced offshore at a floating production unit (FPSO) from 2014.

The Norwegian government resolved in 2001 that the consequences associated with a year-round petroleum activity in the Barents Sea and the Lofoten area had to be accounted for before the activity in these areas were to continue [12]. Numerous reports on the subject were produced in the following years, ultimately leading to a re-opening of the areas (with certain exceptions) in 2003.

Discoveries around the Snøhvit and Goliat development and positive feedback from exploratory drilling in "Hammerfestbassenget" and in the east part of the Barents Sea resulted in additional interest in the area. The large discoveries on the Russian side of the Barents Sea have also resulted in an increased interest on the Norwegian side, where several companies have expressed their interest in expanding and developing new infrastructure further east on the Norwegian mainland [12].

The recent year there have been several interesting prospects in the Norwegian part of the Barents Sea where several have been the subjects of exploratory drilling. The exploration wells Norvarg, Isbjørn, Skrugard, Nucula, Tornerose, Ververis and Arenaria are some the sources for input data to this thesis. These prospects in particular are interesting because they extend further north and east than any other prospects in the Norwegian part of the Barents Sea.

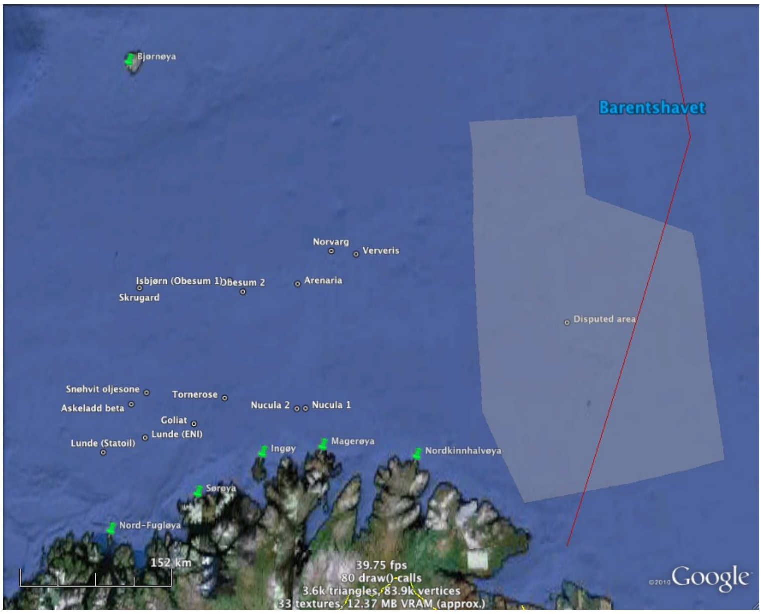


Figure 2.1: Overview over recent exploratory drilling in the Norwegian part of the Barents Sea

The exploration well Norvarg will according to the plan be drilled in the middle of 2011 by Total E&P Norway. Norvarg is located 195 km from the nearest coast and with a water depth in the area of 370 meter. It is expected to find fluids with similar properties as those at the Goliat field, with a gas to oil ratio of 65 Sm3/Sm3 [13]. The license group consists of Total E&P Norway (Operator - 40%), Aker Exploration (20%), North Energy (20%) and Rocksource (20%). According to Rocksource' independent estimate, the recoverable amount of resources from Norvarg is 270 million barrels of oil equivalents [14]. The succession rate is estimated to 50%.

Isbjørn was drilled in 2008 at a water depth of 370 meter, 175 km off the nearest shoreline at Ingøy in Måsøy municipal. Hydro was the operator, but after exploratory drilling was completed a development of the prospect was considered not to be likely. However, the process around the exploratory drilling gave useful information on environmental risk associated with drilling activity in this area due to the operator's thorough assessments.

Skrugard is operated by Statoil, located 200 km off the nearest coast with a water depth in the area of 373 meter. While Statoil is the operator with 50% interest, ENI Norway and Petoro have interests on 30% and 20 % respectively. Statoil announced on April 1 2011 that they have completed an exploratory drilling well at the field and that the prospect contained a considerable amount of hydrocarbons. They also announced that the size of the finding is about 150-250 million barrels o.e, where about 30% of this is reported to be gas. This calls for a standalone development, and Statoil hopes the field will be operating in between 6 and 10 years. The Skrugard prospect is one of the most promising prospects in the Barents Sea (except those already in late development stages) to this date.

Nucula is located closer to the coastline, with a distance of 44 km to Knivskjellodden in Nordkapp municipal. The water depth at the location is 290 meter. The exploration well was drilled in the first quarter of 2007 from January to March and several formations were penetrated with varying content and characteristic. Hydro was the operator of the field with 30% interest. ENI Norway had 30% interest, while BG and Petoro both had 20% interest. As of the current activity status, a development of the field is considered to be not likely [15].

Tornerose is situated in the Hammerfest Basin, ca. 55 km east of the Snøhvit field with a distance of 70 km to shore. The exploration well 7122/6-2 was drilled in 2006 during August and September by the semi-submersible drilling rig Polar Pioneer. The water depth in the area is 404 meter. The results from the drilling showed no movable oil in the formations, but some gas was found and the possibility to produce these at the Melkøya gas treatment plant was discussed. The environmental risk assessments conducted prior to the exploratory drilling process gave valuable information of a potential oil spill in the area.

Ververis was drilled in 2008. The prospect is located 193 km offshore and the water depth at the location is 331 meters. The assessments carried out prior to the drilling indicated that the oil in the formations would have similar characteristics as those at the Goliat field. No oil was found at the Ververis field, but a decent amount of recoverable gas resources was found. It has currently not been decided to develop Ververis as a field, as the discovery has not year been fully evaluated.

Arenaria proved to contain some gas after StatoilHydro drilled the exploration well 7224/6 in 2008. The prospect is located with a distance of 162 km to the nearest shoreline, and the water depth in the area is 267 m. The results from the exploratory drilling have not yet been fully evaluated and it is thus too early to decide whether the prospect will be further developed or not [12].

2.6. The Macondo blowout - Gulf of Mexico 2010

April 20th 2010 a blowout occurred from the Macondo well 76 km off the coast in the Gulf of Mexico, causing the drilling rig Deepwater Horizon to explode. Transocean operated Deepwater Horizon on contract for BP. The rig sank April 22nd after burning for 36 hours [16]. The accident caused the loss of 11 lives, and came to be the biggest offshore oil spill in history after 780000 Sm3 of oil leaked out over 87 days [17].

2.6.1. Definitions and drilling terminology

A conductor is used at the seabed to stabilise the loose sediments at an early stage of the drilling. The blowout preventer (BOP) is attached on top of the wellhead and acts as a safety valve that enables closing of the well either from the drilling unit or by a remotely operated vehicle (ROV). Casings are used inside the drilled hole in combination with cement in order prevent the well from caving in as the well gets deeper. As the well is drilled deeper, casings with slightly lower diameter than the last are submerged into the hole and cemented in place, leading the well to have a decreasing diameter from the seabed to the reservoir. The diameters are selected based on the expected reservoir conditions at the location of drilling.

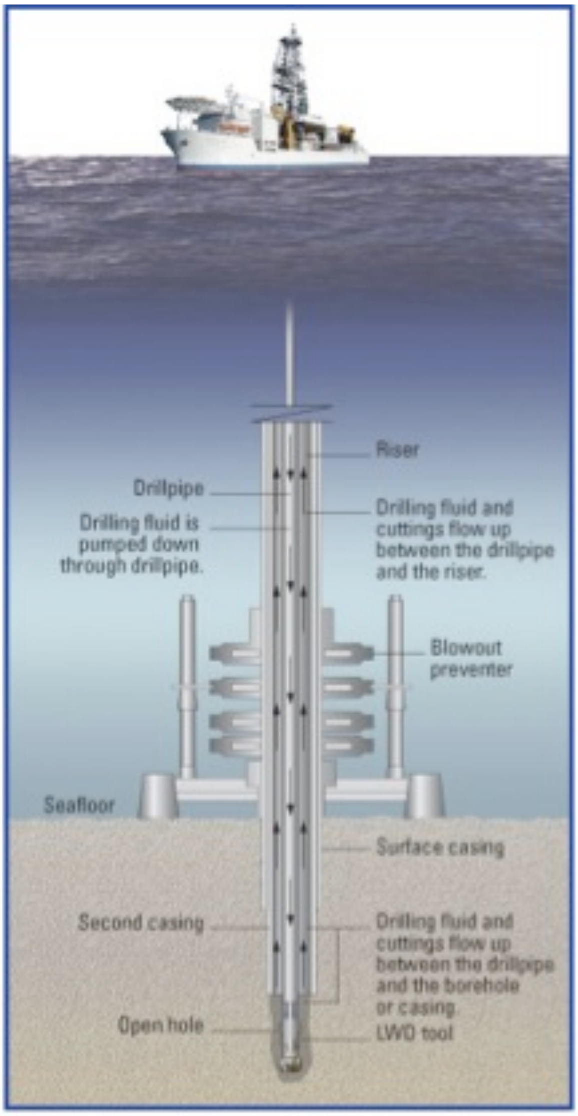


Figure 2.2: *Coarse well diagram with indicators for well flow.*

Drilling mud is used in order to maintain pressure control over the well during the drilling. The mud is pumped down from the drilling unit at the sea surface to the drill bit at the bottom of the well and serves several functions. The primary function of the drilling mud is to maintain well control, but also serves as a coolant for the drill bit and it transports cuttings from the drill bit to the rig deck. In order to maintain well control, the pressure created from the drilling mud column has to be equal to or exceed the pressure encountered from formations during the drilling. If the pressure in a (oil/gas/water) formation encountered when drilling exceeds the pressure of the drilling mud column, the drilling mud may be forced upwards together with the formation fluid in what is commonly known as a kick. The BOP is activated to stop the upward movement of the fluids and to regain control over the well. If the BOP fails to effectively shut down the well, formation fluids will flow to the surface in what is known as a blowout.

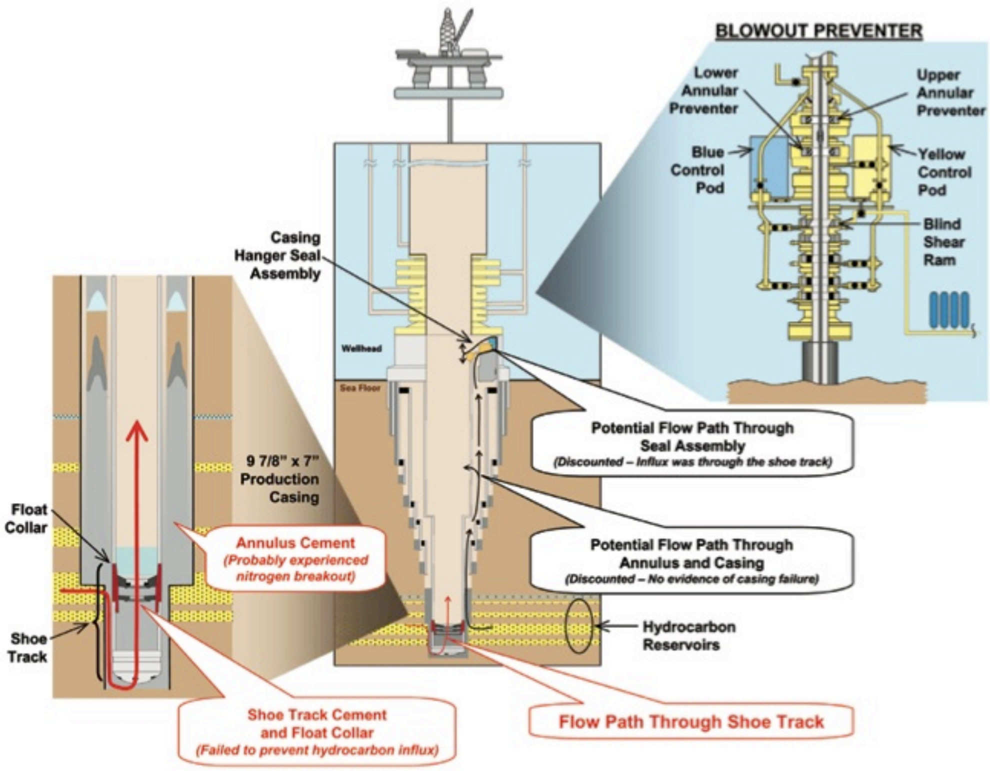


Figure 2.3: *The Macondo well. Ref. Figure 1 from [16].*

As mentioned above, a kick occurs when the pressure in the formation of oil, gas or water exceeds the pressure created by the drilling mud column. This may happen as a result of several operational factors [17]:

1. Higher pore pressure than expected
2. Lower drilling mud pressure than expected
3. Temporarily reduced drilling mud pressure as a result of operational conditions
4. Combinations of 1-3
5. Loss of mud to sea or formation, and thus reduced height of the drilling mud column

2.6.2. Description of the accident

During the drilling of the Macondo well, the drilling procedure had to be changed as a result of encountering higher pressures than first estimated. A sidetrack also had to be drilled as some problems related to well control occurred in the original well. The Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE, formerly known as MMS) approved the changes made to the original drilling procedure. Drilling of the well was completed April 9th. After installing the production casing it was decided that it was no need to carry out a cement bond log. This conflicts with general requirements worked out by BP. The production tubing was tested April 20th, and the negative results (higher pressure in the formation than in the drilling mud column) were approved. In light of what happened afterwards, questions were raised to whether the decision was right to approve the negative test and the quality of the test itself [17]. Drilling mud were deliberately being replaced with sea water, an operation that continued even though the well gave feedback that should have been alarming to the operators. About 95 minutes after the negative pressure test were first approved, drilling mud burst out on the rig floor at 21.40 April 20th. The BOP was activated, but it seemed to have malfunctioned even though instruments confirmed its activation. The first explosion occurred at 21.49, and between 22.00 and 23.22 115 people were evacuated and 11 reported missing [16]. Deepwater Horizon sank April 22nd at 10.22 [16].

2.6.3. Causes of the accident

BPs internal investigation team revealed eight key findings related to the causes of the accident [16]:

1. The annulus cement barrier did not isolate the hydrocarbons
2. The shoe track barriers did not isolate the hydrocarbons
3. The negative-pressure test was accepted although well integrity had not been established
4. Influx was not recognized until hydrocarbons were in the riser
5. Well control response actions failed to regain control of the well
6. Diversion to the mud gas separator resulted in gas venting onto the rig
7. The fire and gas system did not prevent hydrocarbon ignition

8. The BOP emergency mode did not seal the well

The barriers implemented to prevent a blowout can be illustrated in Figure 2.4. The holes in the barriers represent barrier failure, and the arrow that passes through the holes illustrates that all of the barriers have to fail one after the other in order for a blowout to occur.

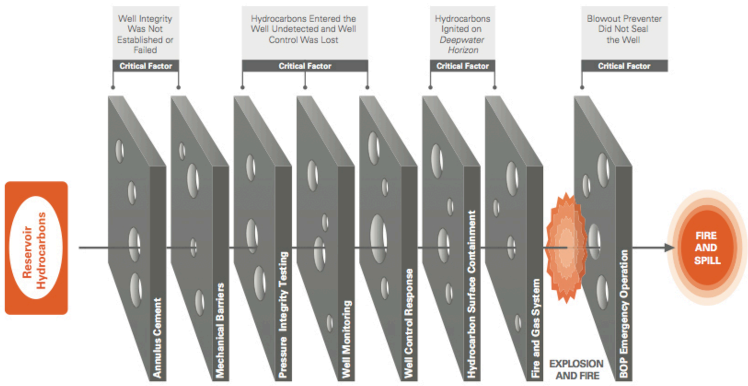


Figure 2.4: *Barrier failure that led to the Deepwater Horizon oil spill accident. Ref. "Figure 1. Barriers Breached and the Relationship of Barriers to the Critical Factors" from* [16].

2.6.3.1. Root causes

It is natural that there are uncertainties connected to the technical causes of the accident. However, reports suggests that there are no such uncertainty about the root cause of the accident [18]. *The National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling* goes as far as saying that "the most significant failure at Macondo - and the clear root cause of the blowout - was a failure of industry management" [18]. Management and communication between BP, contractors such as Halliburton and Transocean, and the government were all of questionable quality. BP did not formally review changes to the drilling procedure and well design and risks associated with the changes were not adequately identified. *The National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling* considers Halliburton's testing of the cement used and communication of test results to be insufficient, and that "it is difficult to imagine a clearer failure of management or communication" [18]. Halliburton's insufficient testing appears to have been known to BP personnel without BP taking any actions to assure the quality of the tests. The report from the National Commission also suggests that a lot of the management decisions that were made saved the companies involved a lot of time and money, but also led to an increased blowout risk from the Macondo well [18].

2.6.4. Environmental consequences of the accident

Comprehensive data on environmental conditions in the Gulf of Mexico prior to the Macondo blowout was generally lacking [18], and thus assessing possible changes made to the ecosystems as a result of the blowout are proved to be hard. In addition, the time since the accident happened is short, and the environmental consequences related to the accident may be hard to investigate and will not appear as clear until the results from long-time monitoring is presented.

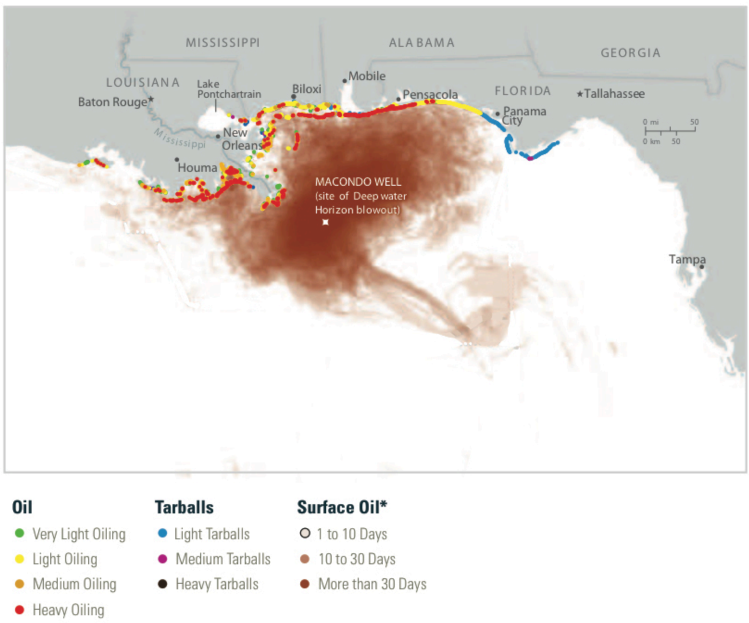


Figure 2.5: *Surface spreading from May 17 - July 25. Most severe shoreline oiling observed through November. Ref. fig. 7.1: "Maximum Extent of Oil" from [18]*

The relative favourable conditions for oil degradation in the Gulf of Mexico have contributed to degradation of a substantial volume of the spilled crude. The warm temperature contributed to an increased amount of evaporation and biodegradation, and the oceanographic- and metrological conditions present at the time contributed to keeping most of the oil offshore and away from the Florida Strait. Oil hit over 1000 km of shoreline, whereas over 200 km were moderately to heavy oiled [18]. The oil that hit shore were considered to be fairly weathered, meaning that is had depleted most of its volatile compounds.

BP used a significant amount of dispersant both on the sea surface and directly into the flow on the sea bottom. Whether the excessive use of dispersants was beneficial with regard to the ecosystems in the Gulf of Mexico remains to be assessed, but it have been questioned by scientists and researchers. The dispersants used in the Gulf of Mexico is generally considered to be less environmental friendly than the ones used on the Norwegian Continental Shelf. This is due to the general composition of the oils in the Gulf of Mexico vs. the Norwegian Continental Shelf.

Certain areas that were closed for fishing immediately after the accident were re-opened in September after investigations showed no oil pollution chemicals in fish or shrimp [17]. The area of impact from the oil spill overlapped with spawning grounds for tuna. The tuna stock in the area is in poor shape and there are expressed concerns towards the recruitment of the stock [17]. Several species of birds, reptiles and marine mammals were also affected by the oil spill, but the exact impact the oil had on these species will not be clear until long-term studies are finished.

2.7. The Gulf of Mexico vs. The Barents Sea

This part of the theoretical background is to a great extent based upon the Norwegian Forum for Collaboration on Risk's independent report on the accidental blowout at the Macondo prospect in the Gulf of Mexico in 2010, ref. [17].

2.7.1. Oceanographic characteristics

The depths in the Gulf of Mexico extend all the way down to ~4500 meters and contain a shallow continental shelf around large parts of the coastline. The width of the shelf varies from about a couple of kilometres in the western parts to several hundred of kilometres in the northern, eastern and southern parts. The Gulf of Mexico consists of a large and almost fully enclosed ocean basin and receive water input from the large rivers Mississippi and Rio Grande [17]. The most characteristic circulation feature in the gulf is the loop current (LC) that flows in through the Yucatán canal towards the continental slope and shelf before turning and flowing out through the Florida Strait. This loop current tend to form a loop current ring inside the gulf, creating a circular flow pattern with current speeds up to 1 m/s. During the period of the Deepwater Horizon blowout this phenomenon did not occur. This prevented oil polluted water from moving to the Atlantic Ocean from the gulf and thus reducing the total spreading of the oil.

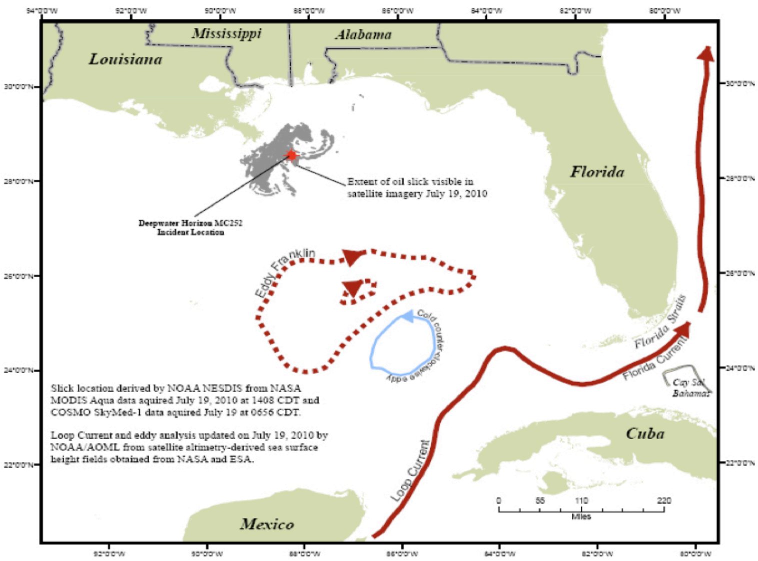


Figure 2.6: *Loop current in the Gulf of Mexico during July 2010. Ref. fig. 4 from [17]*

The continental shelf surrounding the Norwegian mainland has an average depth of 300 meters, and contains numerous banks and troughs. The dominating current alongside Norway is a branch of the North Atlantic Current called the Norwegian Coastal Current. The Norwegian Coastal Current is a north easterly flowing current that goes along the coast of Norway from the North Sea to the Barents Sea. The spreading of the current in the Barents Sea is illustrated in Figure 2.7.

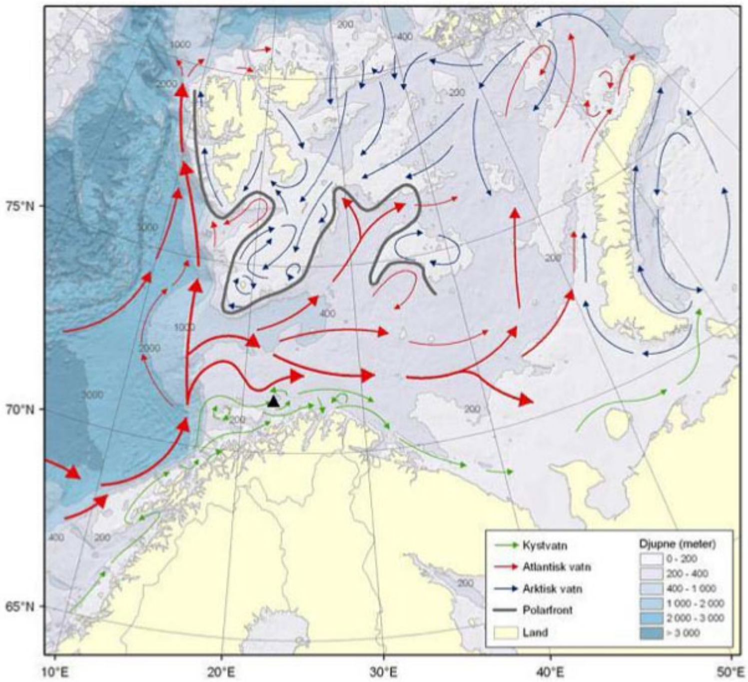


Figure 2.7: *Ocean currents in the Barents Sea. Ref. fig. 7.4 from [19].*

2.7.2. Environmental characteristics

The environmental characteristics in the Barents Sea are quite different from those in the Gulf of Mexico. However, even though species, habitats and general conditions may vary, there are also several comparable factors between the two.

The processes that cause production of plankton are different in the Gulf of Mexico and the Barents Sea. Upwelling causes most of the plankton production in the Gulf of Mexico, whilst seasonal mixing of nutrients causes it in Norwegian water bodies. This is an important aspect, as the produced plankton is the basic nutrient for a lot of species in their early stages of life. Thus, if environmental pollutants interfere with the production of plankton it will also indirectly interfere with the exposed species' ability to acquire nutrients.

The fish species in the Gulf of Mexico are quite different to those in the Barents Sea. The species in the Barents Sea are fewer, but are on the other hand larger in numbers and biomass than compared with the ones in the Gulf of Mexico [17]. Another distinctive feature is that the ecosystems in the Barents Sea is more dynamic with seasonal differences and fluctuate more in terms of population size. Certain species' spawning is also of concern in the Barents Sea. The spawning for these species occurs in a short period of time and at a restricted area. This is of interest when studying vulnerability of species. The conditions for marine mammals are also quite different in the two areas. The Gulf of Mexico consists of a geographically limited area, while the Norwegian seas are larger and are connected to vast ocean bodies such as the Atlantic Ocean and the Arctic Ocean. The Norwegian Sea, the area outside Lofoten and the Barents Sea are all important feeding grounds for large whale species, while smaller marine mammals such as dolphins dominate the Gulf of Mexico [17]. The Barents Sea also contains several seal species that cannot be found in the Gulf of Mexico.

The Gulf of Mexico contains several important areas for birds. BirdLife International have selected 65 Important Bird Areas (IBA) in the area [17]. These IBAs are located in the marshes, mangrove swamps and beaches that surround the gulf. The Gulf of Mexico contains little or few pelagic sea birds, even though some studies show large seasonal variations [17]. The Barents Sea contains several species of high national and international importance and 30 IBAs are selected in the area. During the summer, about 20 million individual seabirds inhabit the Barents Sea. The Barents Sea contains several important sea bird colonies and as opposed to the Gulf of Mexico, the Barents Sea also contains a lot of pelagic sea birds that spend a lot of time on the open ocean. Brünnich's Guillemot, Little Auk, Atlantic Puffin, Black-legged Kittiwake and Northern Fulmar are the most abundant species in the Barents Sea.

Table 2.3: *Vulnerability of species [17].*

Vulnerability	Low	Moderate	High
Species	Terns, gulls, skuas, Red-necked Phalarope	Procellariiformes, diving ducks, storm-petrels and divers	Auks, cormorants, gannets, sea diving ducks and divers

As Table 2.3 suggests, the Barents Sea appears to contain many of the species characterised with a high vulnerability to oil pollution, while the coastal birds in the Gulf of Mexico are characterised with a lower vulnerability to oil pollution [17].

2.7.3. Reservoir characteristics

2.7.3.1. The Gulf of Mexico

The water depth where Deepwater Horizon drilled at the Macondo prospect was approximately 1500 meters. The top of the reservoir is located at 5500 meters depth, with a reservoir pressure of 825 bars and a temperature of 128 °C. The gas-to-oil ratio was estimated to be 500, indicating light oil. The gas-to-oil ratio will affect the blowout ratio, as the blowout ratio increases with increasing gas content in the oil. It is estimated that 9900 Sm3/day of oil was initially released from the Macondo prospect after the Deepwater Horizon accident. As the work with shutting down the well was succeeded, the blowout rate had been reduced to 8400 Sm3/day as a result of a decrease in reservoir pressure. An estimated 780000 Sm3 of oil was released from the well as a result of the Macondo blowout. The geological conditions at the Macondo prospect are considered to be normal for reservoirs at the same depth at other locations in the Gulf of Mexico.

2.7.3.2. The Barents Sea

The Barents Sea is a relatively shallow sea. The deep sea areas outside the Barents Sea rest almost exclusively on a sea floor crust that is younger than 60 million years, which leads scientist to think that the possibility to discover oil in these areas are low. There is not expected to discover reservoirs at the continental shelf and the continental slope outside the northern part of Norway with high pressure or high temperature. These expectations are based on the geological history that shows an elevation of the shelf area that resulted in a reduction in pressure and temperature. It has not been found geological conditions in the Barents Sea that may lead to the combination of reservoir characteristics that were present at the Macondo prospect in the Gulf of Mexico.

2.8. Weathering of spilled oil in the marine environment

Several complex processes contribute to the dispersion and degradation of oil that is discharged into the marine environment. In the aftermath of the Macondo blowout in the Gulf of Mexico during the summer of 2010, it is estimated that as much as 16% of the oil was naturally dispersed and as much as 25% was evaporated or dissolved [18].

The process of degradation and dispersion of oil in the marine environment is termed weathering. Weathering can include spreading, dispersion, sedimentation, evaporation, emulsification, dissolution, biodegradation and oxidation [20]. Most of these processes lead to the disappearance of oil from the sea surface, whereas others promote its persistence. Ultimately, the long-term process of biodegradation breaks down the oil. The time it takes to biodegrade oil depends on factors such as the quality and type of oil, location of the oil spill and prevailing weather and sea conditions.

2.8.1. Description of processes

The following description of weathering processes is to a great extent based upon lectures given by associate professor Jonny Beyer in the course MOT490 Offshore industry and external environment during the fall of 2010.

Spreading of the oil occurs as soon as the oil is discharged into the marine environment. The speed of spreading depends to a great extent upon the viscosity of the oil, with factors such as sea state, wind conditions and volume spilled also contributes to the speed of spreading. Low viscosity oils spread faster than high viscosity oils. Spreading is rarely equal in all directions, and most often the oil slick will break up after a few hours and form narrow bands parallel to the wind direction.

Natural dispersion is the process where oil is broken down into droplets by physical mixing of the water. Wind and turbulence at the sea is the main contributor to this. When the oil slick is broken into droplets, heavier droplets tend to flow back to the surface while some of the smaller droplets will remain suspended in the water column. The smaller droplets that remains in the water column now has a greater surface area than before the dispersion occurred. This allows for faster weathering by processes such as dissolution, biodegradation and sedimentation.

Sedimentation is the process where oil or oil residues settles on the sea bottom. Crude oil is often lighter than seawater and will thus not sink unless it is either broken into a heavier product or the density of the water is changed. Sedimentation in seawater usually occurs if particles of sediment or organic matter are combined with the oil. Oil that have caught fire often forms residues that can be sufficient dense to sink.

Evaporation depends to a great extent upon the volatility of the oil. Light and volatile compounds will evaporate more and faster than heavier compounds. Petrol, kerosene and diesel oils are typically light products that tend to evaporate fast. Evaporation also tends to increase as the oil spreads, due to the increased surface area of the oil slick.

Emulsification is a process where seawater droplets become suspended in the oil. Physical mixing caused by turbulence at the sea surface is the main contributor to emulsification. The emulsion that is formed is often referred to as "chocolate mousse" due to its appearance. The mousse is also very viscous and more persistent than the original oil. If certain conditions are present, the emulsion may return to its original form. These conditions are often present when the oil is stranded on shorelines or under calm and warm conditions at sea.

Dissolution is considered to be one of the less important processes when considering the removal of oil from the sea surface. This is due to the fact that compounds favourable for dissolution also is among those that evaporate first, where evaporation occurs a lot faster than dissolution. The dissolution of components favours conditions where oil is finely dispersed in the water column. Light aromatic hydrocarbons are considered to be among those that are most soluble in seawater.

Biodegradation is the process where microbes degrade oil to water-soluble compounds and ultimately to carbon dioxide and water. There are great variations in what products of the oil that is easily biodegraded and what products that is resistant to biodegradation. The level of biodegradation depends on the temperature, the oxygen level and level of nutrients in the seawater, particularly nitrogen and phosphorus. The biodegradation increases if the oil droplet surface area increases as more of the oil is exposed to the oxygen-rich oil-water interface. This implies that dispersed oil, either naturally dispersed or chemically dispersed, is more prone to biodegradation.

Oxidation is the process where oil reacts with oxygen and is broken down into soluble products or persistent compounds. These persistent compounds are also known as tars. Sunlight acts as a catalyst for this process. Oxidation is a very slow process, and has a tendency to increase the persistence of the oil as a whole. Tarballs found on shorelines close to an oil spill are a typical result of oxidation.

2.9. Environmental resource databases

The following two sources, MRDB and SEAPOP, have been used in this thesis to give background information on the occurrence and extent of marine environmental resources in the area of interest. This subsection gives a brief introduction to the sources.

2.9.1. Marine Resource DataBase (MRDB) [21]

Marine Resource DataBase is a GIS-based database that contains information on vulnerable ecological resources in Norwegian waters. The Norwegian Clean Seas Association for Operating Companies, the Norwegian Coastal Administration, the Norwegian Climate and Pollution Agency and the Norwegian Armed Forces finances and owns the Marine Resource DataBase, while DNV has the responsibility to operate, maintain and develop the database. NOFO is the oil spill response association for operators in Norwegian waters, and the operators contribute indirectly to the database through this organisation. The purpose with MRDB is to gather and organize information on marine environmental resources in Norway, and make them available to interested parties in a user-friendly format.

It was the operators on the Norwegian shelf together with the Norwegian Climate and Pollution Agency that decided to establish MRDB in 1989. The database was established based on needs and demands from the operators and the governmental bodies. MRDB covered the Norwegian coastal zone, the Norwegian economic zone and the area around Svalbard by 1993. MRDB became a registered trademark in 1996.

2.9.2. SEAPOP [22]

SEAPOP (derived from Seabird Populations) was established in 2005 as a long-term monitoring and mapping program for seabirds in Norway. Norwegian Institute for Nature Research organizes SEAPOP in cooperation with the Norwegian Polar Institute and Tromsø University Museum. The Ministry of the Environment, the Ministry of Petroleum and Energy, and the Norwegian Oil Industry Association finances SEAPOP. The Norwegian Coastal Administration, the Norwegian Institute for Water Research and the Norwegian Polar Institute contributes to the program as consultants.

3. Methodology

3.1. Case study

3.1.1. Scenario

The case study carried out in this thesis is based upon scenarios where a blowout occurs in the former disputed area between Norway and Russia in the Barents Sea. The blowout occurs during exploratory drilling with a semi-submersible drilling rig. The rig is located at 73° 0'6.00"N, 32°30'0.00"E, approximately 258 km off shore, at the time of the accident. The prospect of interest contains mainly oil with characteristics similar to the one found at the Goliat field.

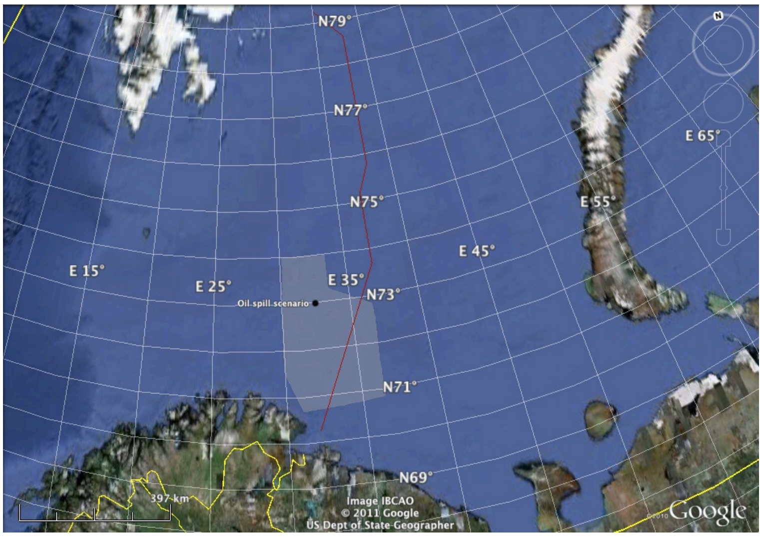


Figure 3.1: *Location of the accidental blowout scenario used in this thesis.*

The oil is discharged on the seabed, and the semi-submersible drilling rig is able to disconnect and leave the area without taking damage. Due to a series of unforeseen events, the duration of the blowout reaches 100 days. The initial oil drift data will be presented as weighted rates and durations for all seasons both subsea and topside, while the long-term oil drift data will be presented for chosen rates and durations of 35 and 100 days.

3.2. Method for assessing environmental risk

In order to assess the environmental consequences associated with such an accident, the modelled oil drift was compared to the presence of valuable ecosystem components. Due to the limitations of this thesis, a limited number of components were included in this work. The selection of species to include was based on their value and vulnerability, and was made in conformance with the reports associated with the updating of the management plan for the Barents Sea and Lofoten area (2011).

3.3. Background for input to the oil drift model

Many of the following assumptions and considerations are based upon reports from the Goliat development in the Barents Sea. The Goliat field will be the first oil producing field in the Barents Sea, and thoroughly reports from this development is often used as a reference for other exploratory fields in the area. It should be noted that the characteristics of an oil reservoir will vary depending on the location, but as there is little knowledge available for the characteristics in the area this thesis discusses it have been chosen to base the assumptions on the field associated with the most reliable and thorough studies.

In addition to using knowledge about the Goliat field, thorough reports from the Norvarg prospect have been used to establish a basis for the input data. Norvarg is a prospect closer to our area of interest, where thorough assessments of well risk and environmental risk is available. The assessments carried out in connection to Norvarg were published late November in 2010 [13], and are thus one of the most recent studies published about environmental risk close to our area of interest in the Barents Sea. Total E&P Norway is planning to drill the Norvarg well during the summer of 2011 with the semisubmersible drilling unit West Phoenix.

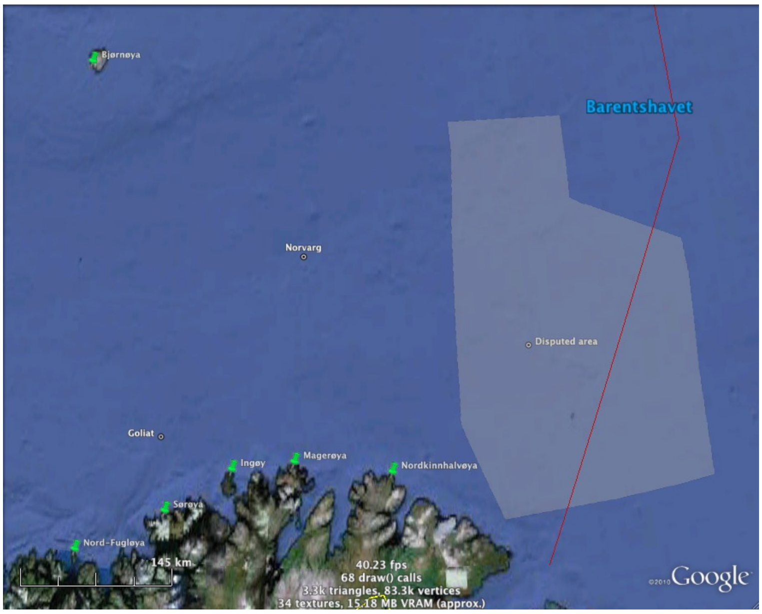


Figure 3.2: *Location of Goliat and Norvarg in the Barents Sea.*

In order to establish a basic understanding and create a basis for the input data, an overview over some of the recent exploratory drilling carried out (or under planning) in the Barents Sea were created. This overview was created to give a somewhat statistical basis to the input data, in addition to the knowledge acquired from Goliat and Norvarg. The overview can be found in Appendix I. Data such as modelling tools used, drilling period, water depth, distance from coast, expected reservoir fluids, weighted blowout rates, duration of blowout, GOR and time used to drill a relief well were all compared and have been used as a basis when deciding input data to the modelling carried out in this master thesis. Norvarg, Lunde, Goliat, Isbjørn (Obesum 1), Obesum 2, Skrugard, Nucula, Snøhvit, Askeladd, Tornerose, Ververis and Arenaria were the exploratory fields included in this comparison study. All of the wells in the comparison study were drilled between 2006 and 2011. Statoil (and StatoilHydro) carried out 9 of the ERAs, 2 were carried out by Hydro, 2 by ENI Norway and 1 by Total E&P Norway. 7 of the 14 ERAs were carried out by DNV as consultant work on behalf of the operator.

3.4. Input to the oil drift model

Rate, duration, oil type and location are input that is needed in OS3D. This chapter describes the background for each of the inputs and the parameters chosen for the oil drift modelling.

3.4.1. Rate

Reservoir pressure is one of the factors that affect the rate of a blowout. The rate for a blowout from the reservoirs Realgrunnen and Kobbe at the Goliat field during the exploratory drilling phase are estimated to vary from 2000 Sm3/day to 20000 Sm3/day [23]. The rate used for modelling a blowout from an exploratory drilling well at the Goliat field is estimated to be 4500 Sm3/day [23]. Information from fields already in production in the North Sea suggest a blowout rate between 1000 Sm3/day and 10000 Sm3/day [24] when assessing environmental risk. This also coincides with the rates from Norvarg, which was estimated to vary from 1100 Sm3/day to 11000 Sm3/day, with weighted rates at 3200 Sm3/day and 2500 Sm3/day. Weighted rates from the comparison study of the other fields in the Barents Sea suggest rates ranging from 366 Sm3/day to 8098 Sm3/day. Weighted rate is the rate that is assumed to be most probable based on the probability distribution for the range of rates.

The stated reason behind the variation in rate is differences in geological conditions and reservoir characteristics such as pressure and flow [25]. Historical information from well kicks in the North Sea, the Norwegian Sea and the Barents Sea considers a rate of 4500 Sm3/day to be representative [26]. Even though a rate of 4500 Sm3/day is considered to be representative, it is by some considered to be high or a bit too conservative [26]. By comparison is the Macondo blowout the worst in history when it comes to rate, with an initial rate of 9900 Sm3/day (later decreased to 8400 Sm3/day) [17]. Rates this high are normally not expected at the Norwegian continental shelf due to geological history and reservoir conditions, except for certain areas in the Tampen area where conservative estimates have reached 8000 Sm3/day [25].

The weighted rates from the compared fields in the Barents Sea (see Appendix I) were categorized to match the format needed as input to the oil drift model. An average blowout rate for both topside and subsea were calculated, and is presented in Table 3.1. These are the rates that will be used as input to the oil drift model in this thesis, similar to how weighted rates are used during an environmental risk analysis process.

Table 3.1: *Categorised blowout rates based on the ERAs carried out for exploratory drilling in the Barents Sea.*

Category	Rate (Sm3/day)	Average blowout rate: Topside (Sm3/day)	Average blowout rate: Subsea (Sm3/day)
1	1000 - 2000	1384	1299
2	2000 - 3000		2412
3	3000 - 4000	3217	3666
4	> 4000	6029	4810

Table 3.2 and Table 3.3 accounts for the number of rates that constitutes the average in the data basis for the selected exploratory fields in the Barents Sea.

Table 3.2: *Rate distribution topside.*

Category	Rate (Sm3/day)	Average rate (Sm3/day)	Number of rates within category
1	1000 - 2000	1384	6
2	2000 - 3000		0
3	3000 - 4000	3359	2
4	> 4000	6029	4

__Table 3.3__: Rate distribution subsea.

Category	Rate (Sm3/day)	Average rate (Sm3/day)	Number of rates within category
1	1000 - 2000	1299	3
2	2000 - 3000	2412	2
3	3000 - 4000	3666	3
4	> 4000	4810	4

These categorized rates can be compared to the rates Safetec have prepared based on statistical data of kicks that have occurred in the North Sea, the Norwegian Sea and the Barents Sea. These rates are presented in Table 3.4. Safetec's rates can because of its good statistical basis be used for fields in Norway where little or no knowledge about the reservoir exists, and is thus important to consider in this thesis.

Table 3.4: *Generic blowout rates based on statistics of kicks in the North Sea, the Norwegian Sea and the Barents Sea.*

Category	Rate (tons/day)	Average blowout rate: Topside (tons/day)	Average blowout rate: Subsea (tons/day)
1	1000 - 2000	1248	1428
2	2000 - 3000	2752	2568
3	3000 - 4000	3221	3214
4	> 4000	4590	6346

3.4.2. Duration

A blowout may stop or be interrupted as a result of one or more of the following mechanisms [17]:

- Bridging - Change in flow pattern without human interference
    - Plugging of the well
    - Global collapse of the well
- Natural stop as a result of:

  - Drop in reservoir pressure
  - Increase in well pressure
  - Gas- or water coning
- Drilling of a relief well
- Direct measures from the drilling rig (capping)
  - Mechanical closing of the well
  - Killing the well with mud and cement

It cannot with 100% certainty be assured that capping and bridging will stop a blowout before a relief well have been drilled. This is something that should be considered when estimating the potential duration of a blowout. The time it takes to drill a relief well at the Goliat field was estimated to be 45 days [23]. This time normally defines the longest possible blowout, even though a blowout may continue after the relief well have been drilled (i.e. the blowout from the Montara oil field north-west of Australia in 2009). For fields in production in the North Sea, the duration of potential blowouts is reported to vary from 40 to 90 days [24] depending on mobilization time and geological characteristics. At the Norvarg field it is estimated that 35 days are needed in order to drill a relief well, yet there is still calculated a 3% probability that a blowout will have a duration of 100 days due to the success rate of relief wells.

Table 3.5: *Example of blowout duration probability distribution [25].*

Duration (days)	< 2	2 - 5	5 - 15	15 - 60	> 60
Probability	51%	16%	19%	12%	2%

Table 3.5 shows a distribution of blowouts with their respective probability. This distribution is based upon historical data from SINTEF's blowout database.

Table 3.6: *Blowout duration probability distribution for the Norvarg exploration well in the Barents Sea [13].*

Duration (days)	< 2	2 - 5	5 - 35	35 - 100
Probability topside	78%	22%	0%	0%
Probability subsea	50%	14%	33%	3%

The blowout probability distribution for the Norvarg field in the Barents Sea suggests that a topside blowout have a maximum duration of 5 days. This is somewhat conservative, and implies that after 5 days the flow of hydrocarbons have either been stopped by intervention or bridging, or turned into a subsea release due to a disconnection of the drilling unit. Disconnection of the drilling unit may either be done by purpose (abandon location) or by accident (explosion or sinking).

An uncontrolled blowout from a well can, as mentioned above, be stopped either by natural causes such as bridging or well intervention such as a top kill or a relief well. As much as 77% of all relevant blowouts in the past has stopped as a result of bridging [27]. This implies that the probability of bridging is essential when assessing the possible duration of a blowout. Due to the geological history of the target formations in the area of Norvarg, the probability for bridging given a blowout at the Norvarg field is considered to be lower than statistical probability of bridging obtained from the SINTEF offshore blowout database. The geological formations at the Norvarg field have been exposed to significant uplift, and thus also a significant reduction of temperature and pressure. This reduction of stress on the formations is believed to have resulted in a reduced probability of bridging [28].

The duration probability distribution calculated for the Norvarg field (see Table 3.6) implies that a blowout will either be stopped by intervention during the first days of the blowout or after a relief well have been drilled. This is shown by the irregular probability tendency, which may have been more linear if the bridging probability were higher.

The duration probability distribution for the Norvarg field will be used as input to the oil drift model due to the similarities between Norvarg and the area of interest in this master thesis.

3.4.3. Amount of oil discharged

The amount of oil discharged from a blowout depends on rate and duration. With the lowest rate (1000 Sm3/day) and the lowest duration (1 day) the amount of the oil spilled will be 1000 Sm3. With the highest rate (20000 Sm3/day) and longest duration (50 days) the amount of oil spilled will be 1,000,000 Sm3 [26]. This implies that there is a huge range in the amount of oil spilled. One can consider the blowout from the Macondo prospect in 2010 to represent the upper part of the sample space with the total amount of oil discharged being equal to 780000 Sm3 [17]. A blowout will thus almost certainly be in the range of 1000 Sm3 to 780000 Sm3.

3.4.4. Oil type

The oil type used for oil drift modelling in this thesis is oil from the Goliat field. There are two formations at the Goliat field, Realgrunnen and Kobbe, each with different characteristics. Kobbe oil is a light oil type on the border to being condensate, while Realgrunnen oil is heavier. In addition to these two, there will in the case of a blowout at the Goliat field also be a blend consisting of 70% Kobbe oil and 30% Realgrunnen oil. Realgrunnen oil is used for modelling the oil spill used in this thesis.

Table 3.7: *Goliat fluid parameters [23]*

Parameter	Realgrunnen oil	Kobbe oil	Goliat Blend
Fluid density	857 kg/m3	797 kg/m3	822 kg/m3
Max water content	70 %	75 %	75 %
Wax content	5,1 weight %	3,42 weight %	3,6 weight %
Asphalten content	0,14 weight %	0,03 weight %	0,08 weight %
Viscosity	257 cP	22 cP	95 cP
GOR	63	215	219

3.4.5. Location

The modelled blowout is located in the former disputed area close to the new delimitation line between Norway and Russia in the Barents Sea. The exact location of the modelled oil spill is 73° 0'6.00"N, 32°30'0.00"E. The water depth in the area is 239 meter, and the distance to the coastline is approximately 258 km. The modelled blowout is located about 195 km east of Ververis and 217 km east of Norvarg.

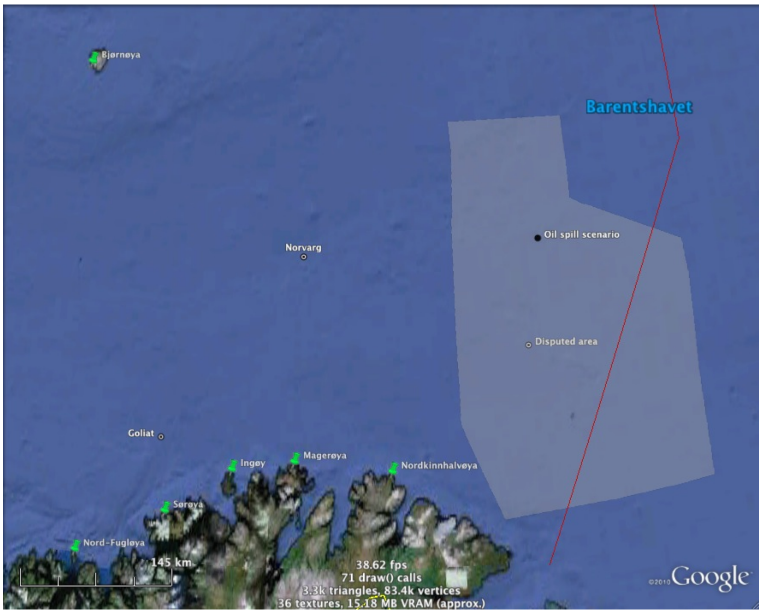


Figure 3.3: *Location of the oil spill modelled in this thesis.*

This area was chosen based on increasing interest from energy companies and this areas increasing probability of being opened. As the treaty between Norway and Russia concerning maritime delimitation and cooperation in the Barents Sea is approved, it is reasonable to believe that the Norwegian authorities will open this area for exploration and production. Old seismic surveys have suggested that there are formations in this area that might contain hydrocarbons.

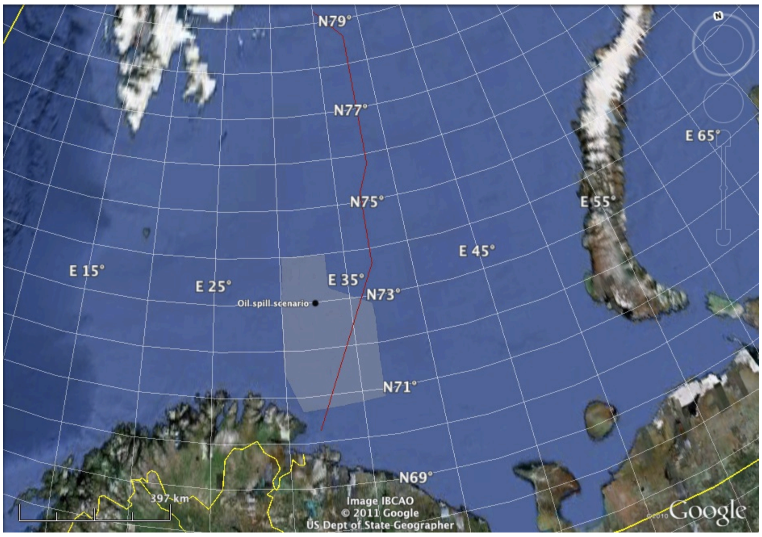


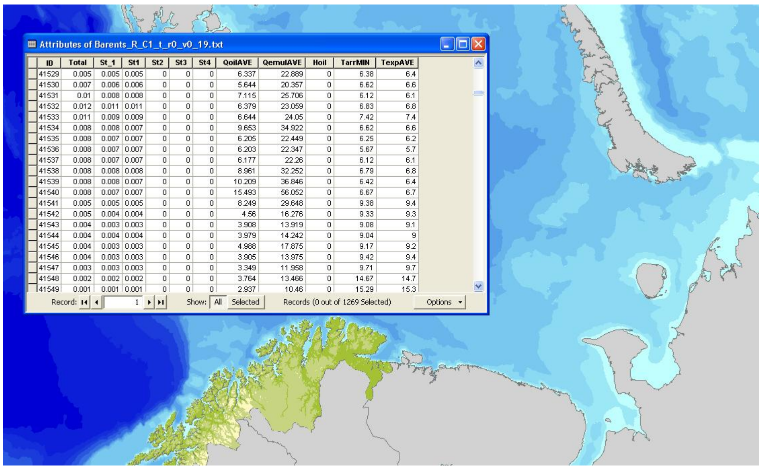
Figure 3.4: *Location of the oil spill modelled in this thesis. Spitsbergen and Novaya Zemlja included for geographical references.*

3.5. Output from the oil drift model

After the input data have been processed by OS3D and post-processed by DNV staff at Høvik, the data had to be visualised in Geographic Information System (GIS) software. This was done with ArcView GIS with help from supervisors from DNV's offices at Stavanger and Høvik.

The output from OS3D was, after post-processing, presented as tables in a text document. The text documents presented the probability that oil would occur within a given geographical area (10x10 km square). The squares were labelled with an ID that indicated a location within the Norwegian economic zone.

It is important to emphasize the fact that the final output from OS3D (Figure 3.8) illustrates the statistical oil drift based on 3600 blowouts, and not oil drift from a single accidental discharge. This cannot be stressed enough, as it is frequently misinterpreted.



ID	Total	St_1	St1	St2	St3	St4	QoilAVE	QemulAVE	Hoil	TarrMIN	TexpAVE
41529	0.005	0.005	0.005	0	0	0	6.337	22.889	0	6.38	6.4
41530	0.007	0.006	0.006	0	0	0	5.644	20.357	0	6.62	6.6
41531	0.01	0.008	0.008	0	0	0	7.115	25.706	0	6.12	6.1
41532	0.012	0.011	0.011	0	0	0	6.379	23.059	0	6.83	6.8
41533	0.011	0.009	0.009	0	0	0	6.644	24.05	0	7.42	7.4
41534	0.008	0.008	0.007	0	0	0	9.653	34.922	0	6.62	6.6
41535	0.008	0.007	0.007	0	0	0	6.205	22.449	0	6.25	6.2
41536	0.008	0.007	0.007	0	0	0	6.203	22.347	0	5.67	5.7
41537	0.008	0.007	0.007	0	0	0	6.177	22.26	0	6.12	6.1
41538	0.008	0.008	0.008	0	0	0	8.961	32.252	0	6.79	6.8
41539	0.008	0.008	0.007	0	0	0	10.209	36.846	0	6.42	6.4
41540	0.008	0.007	0.007	0	0	0	15.493	56.052	0	6.67	6.7
41541	0.005	0.005	0.005	0	0	0	8.249	29.648	0	9.38	9.4
41542	0.005	0.004	0.004	0	0	0	4.56	16.276	0	9.33	9.3
41543	0.004	0.003	0.003	0	0	0	3.908	13.919	0	9.08	9.1
41544	0.004	0.004	0.004	0	0	0	3.979	14.242	0	9.04	9
41545	0.004	0.003	0.003	0	0	0	4.988	17.875	0	9.17	9.2
41546	0.004	0.003	0.003	0	0	0	3.905	13.975	0	9.42	9.4
41547	0.003	0.003	0.003	0	0	0	3.349	11.958	0	9.71	9.7
41548	0.002	0.002	0.002	0	0	0	3.764	13.466	0	14.67	14.7
41549	0.001	0.001	0.001	0	0	0	2.937	10.46	0	15.29	15.3

Figure 3.5: *Output from post-processing of OS3D results in table format.*

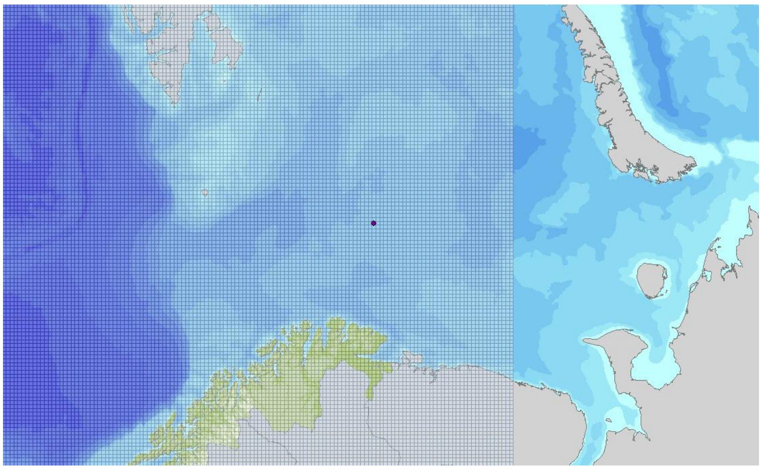


Figure 3.6: *10x10 km grid covering the Norwegian economic zone.*

By combining the squares containing a probability of oil impact with geographical information from ArcView GIS, informative graphics about the extent of an oil spill scenario was created.

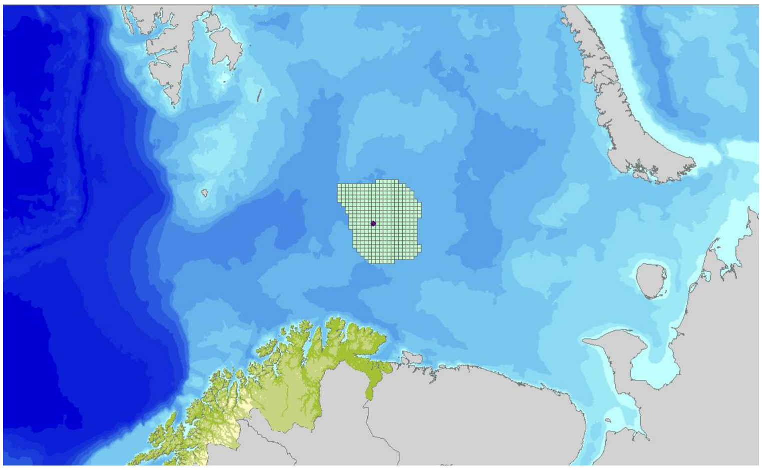


Figure 3.7: *The marked area indicates the area that is affected in over 5% of the scenarios simulated based 3600 simulations, and <u>not</u> the extent of one single discharge of oil.*

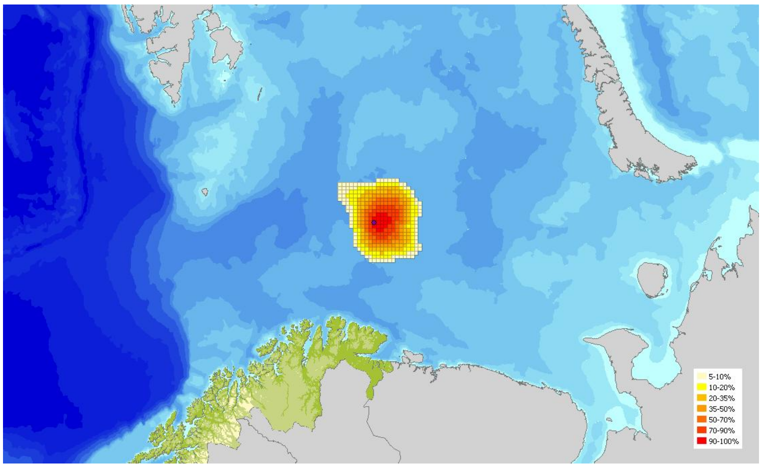


Figure 3.8: *The marked area indicates the area that is affected in over 5% of the scenarios simulated based 3600 simulations, and <u>not</u> the extent of one single discharge of oil. The colour scale indicates an increasing probability that a scenario will affect the given 10x10 km square.*

4. Description of natural resources and environmental characteristics

4.1. Barents Sea physical conditions

The Barents Sea is a shallow shelf sea with an average depth of 230 meters. The water depth in the area of interest in this thesis is 239 meters. Large banks and deep channels dominate the bottom topography in the Barents Sea. Some examples of banks are "Sentralbanken", "Spitsbergenbanken" and "Storbanken" where the water depth ranges from 100 to 200 meters. The "Bjørnøy" channel reaches a depth of approximately 400 meters under sea surface. In the western part of the Barents Sea the water depth increases in the continental slope towards the Norwegian Sea. The sea bottom itself is generally relatively flat with a loose top layer.

The water circulation in the Barents Sea is dominated by the incoming Atlantic current, with a general easterly and northerly surface current. A detailed overview over general current patterns in the Barents Sea is shown in Figure 2.7. There is considered to be three types of water masses in the Barents Sea: Atlantic water, Arctic water and coastal water [13]. The Atlantic water is typically warm (temperature >3°C) and salty (salinity >35), while the Arctic water is cold (temperature <0°C) and less salty (salinity <35). The coastal water is considered to be warm (temperature >3°C) and to have a low salinity (salinity <34.7). The temperature in the Barents Sea is usually between 4 and 6°C and the average water transport into the Barents Sea is approximately 1,5 Sverdrup (1,5 million m^3 sec^{-1}) [23].

4.2. Fauna

A short description of the relevant resources in the Barents Sea fauna is presented below. An overview over the most vulnerable species in the Barents Sea has also been established and is presented in this section. This chapter is to a great extent based upon reports associated with the updating of the management plan for the Barents Sea and Lofoten area (2011).

During an environmental risk analysis process, certain species and elements are chosen to represent the most vulnerable aspects of the environment. These are called Valued Ecosystem Components (VEC), defined as a resource or environmental characteristics that [5]:

- Is important (not only with regard to economic aspects) to local human populations, or
- Have a national or international interest, or
- If changed from the present state, it will have importance for how the environmental impact is considered, and for which mitigated measures chosen

Even though VECs are not used according to environmental risk analysis methodology in this thesis, the criteria for choosing VECs are considered to be relevant. VECs are selected based on their contribution to the overall environmental risk. A given set of prioritizing criteria is used to define components that should be included in the environmental risk analysis [5]:

- VEC must be a population, a community or a habitat
- VEC must have a high vulnerability towards oil contamination in the relevant season
- VEC population must be represented by a high proportion of the population within the area of influence
- VEC population must be present most of the year or in the season of impact
- VEC habitat must have a high probability of being exposed to oil contamination
- Species listed in the Red List for Species within the area of influence should be considered as a VEC.

4.2.1. Fish

The Barents Sea contains several commercially important fish stocks. The Norwegian management of fisheries have proven to be good and reports suggests that health and size of these commercial fish stocks are well monitored and documented [29]. Recent studies also suggests that the stocks of Cod, Haddock and Coalfish are historically high [29].

Cod, Capelin and Herring are the fish species that are considered to be the core of the dynamic ecosystem in the Barents Sea. Damage to these species will affect other species somehow reliant on the core species. We often consider damage to key species of the ecosystems to contribution most to the overall environmental risk, and are thus often chosen as VECs in environmental risk assessments and species of interest for environmental research.

Cod, Capelin and Herring have spawning patterns that makes them vulnerable towards acute oil spills. These species spawn during a short time interval and within a limited geographical area. This makes the spawning individuals, the eggs and the larvae as a whole particularly vulnerable towards disturbance, and the probability of a disturbance affecting entire seasons spawn increases.

On the open ocean, grown individuals have the ability to swim away from oil-polluted water. Fish living in coastal waters have less ability to do this. This contributes to the belief that the environmental risk is higher in coastal areas than on the open ocean.

Cod:

Cod is an important predator in the Barents Sea. It is resilient towards changes in sources of food and prey. Capelin is an important prey for Cod, and the size of the Cod stock will vary as a result of fluctuations in the Capelin stock. Recent studies indicates that spawning stock of the North-East Arctic Cod is at its highest since 1947, with a level of 1,14 million tonnes in 2010 [29]. This is an increase of 63% compared with the 2005 numbers. Cod have historically been one of the most important species for Norwegian fisheries.

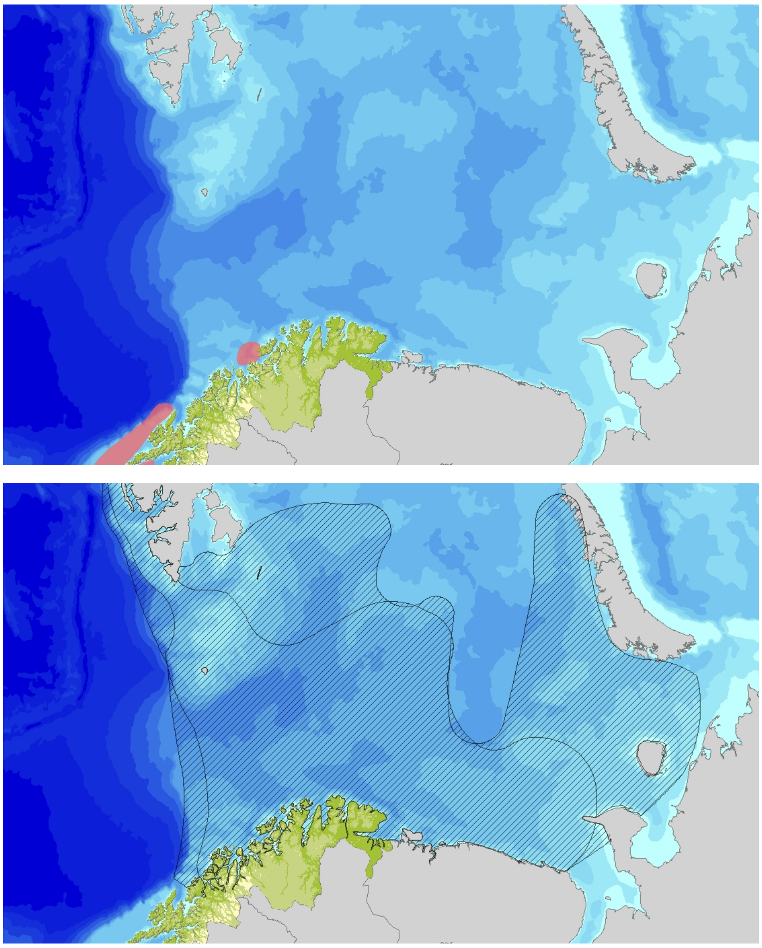


Figure 4.1: *North-East Arctic Cod: Spawning grounds (upper) and occurrence of individuals between 0 and 3 years old (lower). Source: Institute of Marine Research.*

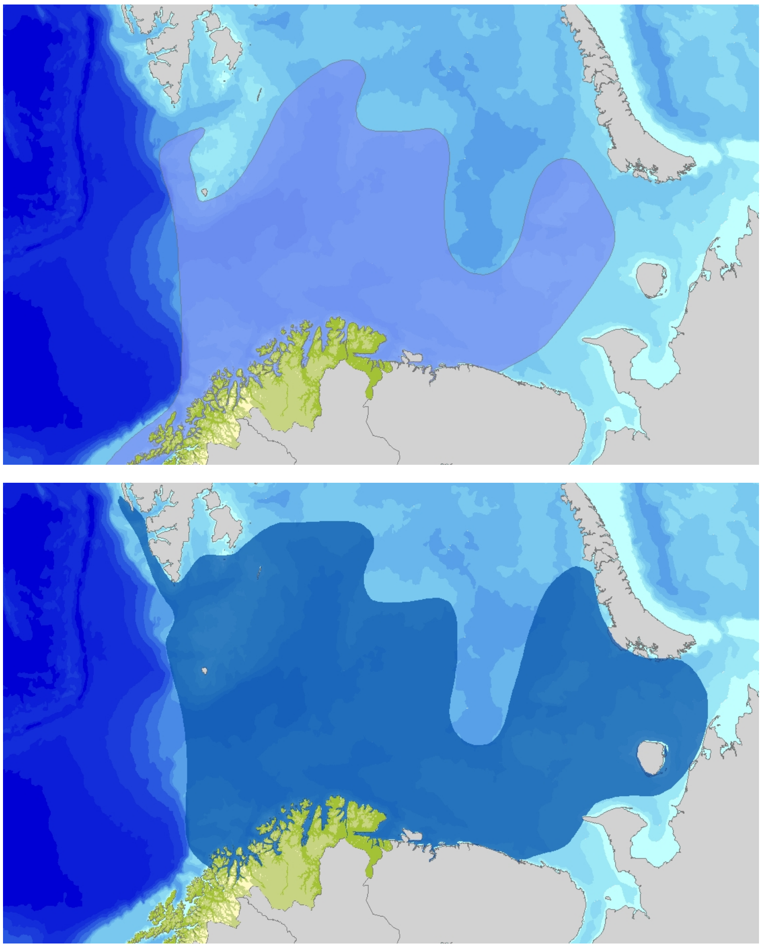


Figure 4.2: *North-East Arctic Cod: Wintering ground for individuals over 4 years old (upper) and feeding ground for individuals over 4 years old (lower). Source: Institute of Marine Research.*

Capelin:

Capelin is a key specie in the Barents Sea. It is a predator on zooplankton and is an important source of food for fish, seabirds and sea mammals. Variations in the Capelin stock will have great effect on associated species both on a higher and a lower trophic level than Capelin.

The majority of the Capelin stock is located north in the Barents Sea, close to the ice edge where it feeds on zooplankton. It migrates south to the Norwegian coastline to spawn. The Capelin larvae migrate north with the prevailing surface currents and provide a nutritious source of food. Young Herring feeds upon Capelin larvae drifting north. The extent of this is large, and it has proven to contribute to collapses in the Capelin stock when the amount of young Herring in the Barents Sea is large. The Capelin stock has collapsed three times since monitoring of the stock started in the 1970s [12]. The first observed collapse in the middle of 1980s proved to have big consequences for the ecosystem in the Barents Sea. The first collapse of the capelin stock led to a collapse in the stock of Common Guillemot, the conditions of Minke whale were worsened, Harp seal migrated great distances in search for prey and the stress towards the Cod stock increased as a result of less prey and increased cannibalism within the stock. The following two collapses in the 1990s and 2000s had fewer consequences due to more alternative prey species available.

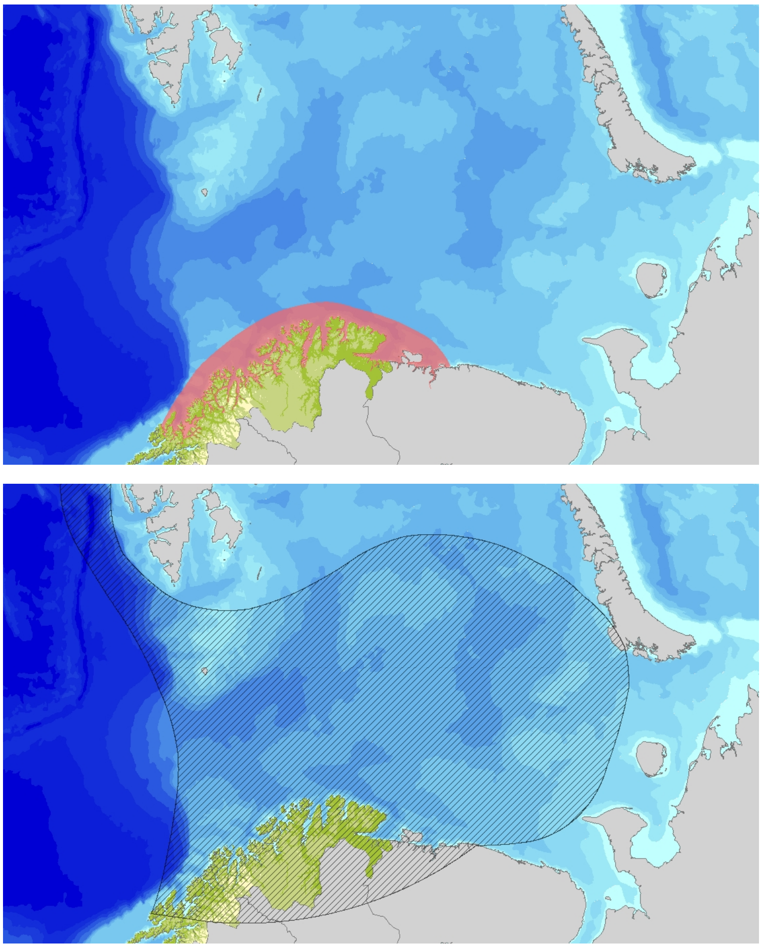


Figure 4.3: *Capelin: Spawning ground (upper) and occurrence of young individuals (lower). Source: Institute of Marine Research.*

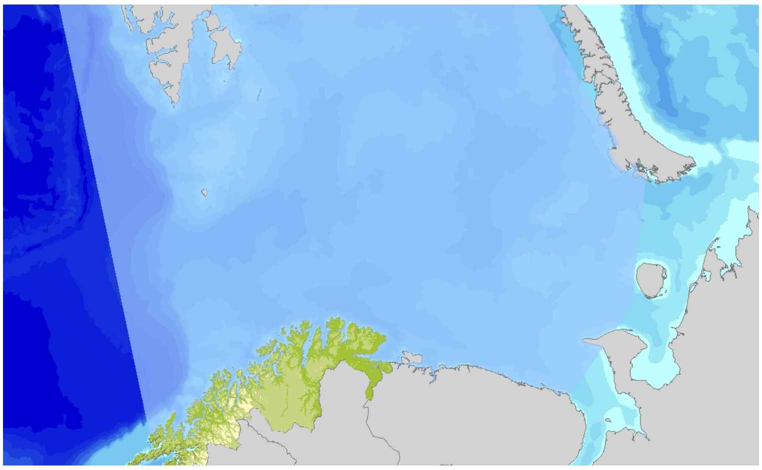


Figure 4.4: *Capelin: Feeding ground - grown individuals. Source: Institute of Marine Research.*

Herring:

The population of Herring in the Barents Sea consists solely of young individuals up to 4 years old. Norwegian Spring-Spawning Herring spawn along the coast of the Norwegian Sea, and the larvae drift with the prevailing ocean currents in to the Barents Sea. This makes the Barents Sea an important area for Herring during the first stage of life. After the 3 or 4 first years, the Herring migrates back to the Norwegian Sea. There is no fishing on young individuals of Herring in the Barents Sea. Herring feed on Capelin larvae, and the sizes of the two stocks are closely related. Herring feeding on Capelin larvae is assumed to be the reason behind the collapses in the capelin stock the last decades [29].

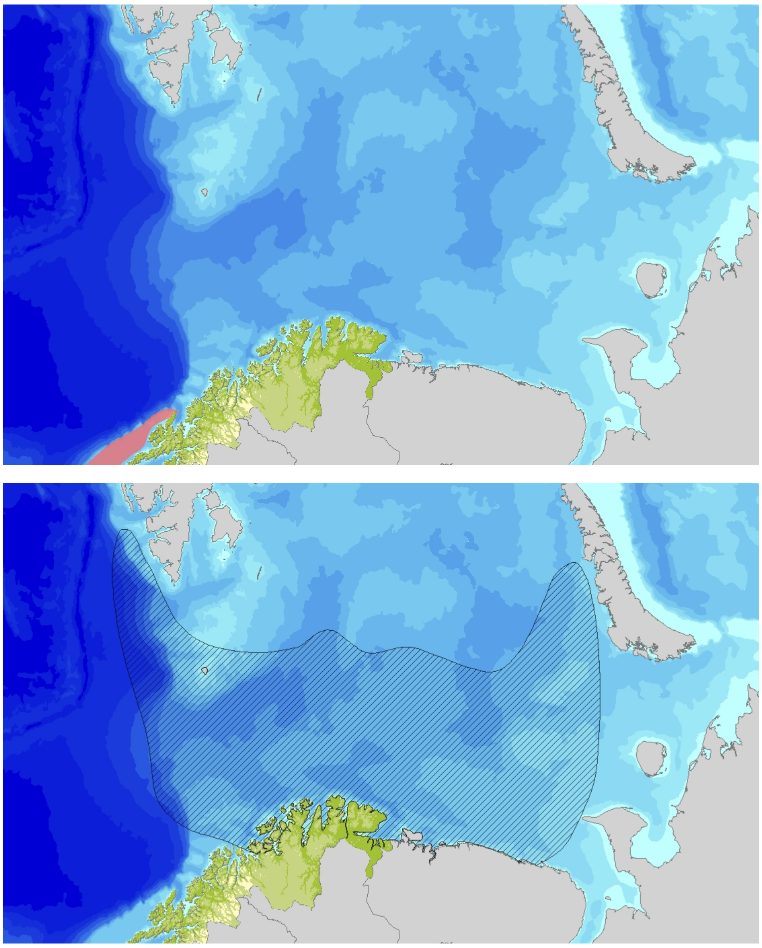


Figure 4.5: *Norwegian spring-spawning herring: Spawning ground (upper) and occurrence of individuals between 0 and 4 years old (lower). Source: Institute of Marine Research.*

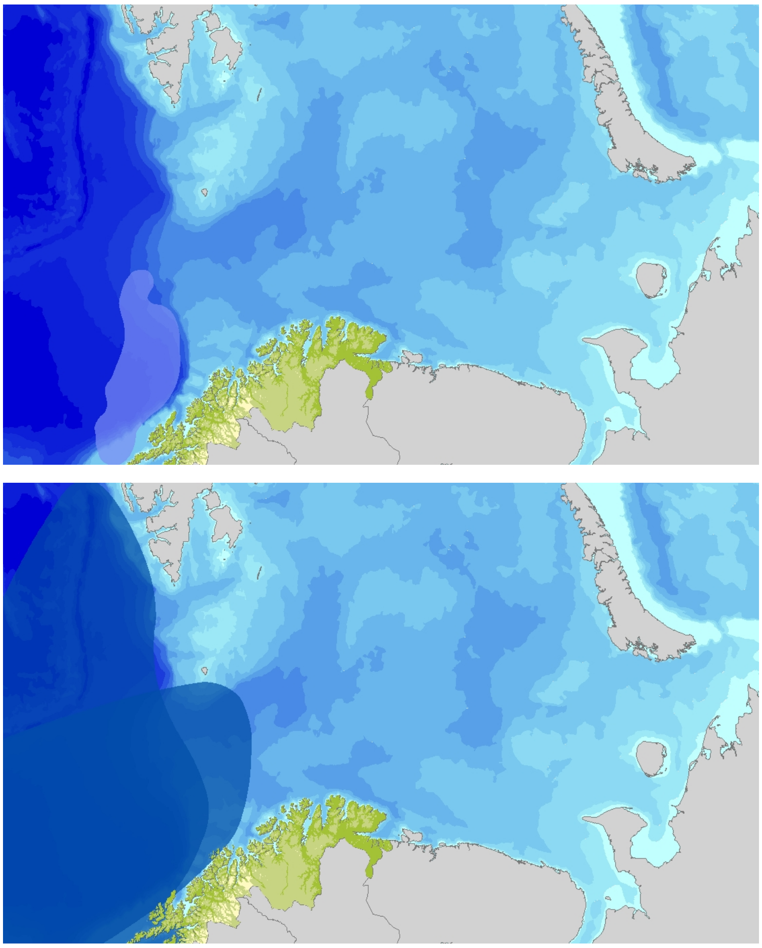


Figure 4.6: *Norwegian spring-spawning herring: Wintering ground (upper) and feeding ground (lower). Source: Institute of Marine Research.*

4.2.2. Marine mammals

Several species of marine mammals inhabits the Barents Sea. Seals dominate in number of individuals and whales dominates in biomass [30]. Grey seal and Harbour seal are generally considered to be the most vulnerable seal species in the Barents Sea. Harbour seal is also listed as vulnerable in the 2010 Norwegian Red List for Species [31]. In addition to the seals, the Otter should also be of concern when assessing impact on the marine mammals due to its status as vulnerable in the red list.

Coastal seals are often considered to be among the most vulnerable marine mammals when assessing environmental risk associated with accidental oil spills. These mammals are in their most vulnerable state when they gather in colonies in coastal areas during their birth- and moulting period. Impact of an oil spill on marine mammals can take a long time to assess as they have relatively long generations. Seal cubs are more vulnerable than grown individuals as they rely on their insulating fur to keep them warm. This fur will loose its insulating ability as it is affected by oil. Oil pollution on grown individuals might lead to infection of wounds and have poisonous effects if ingested.

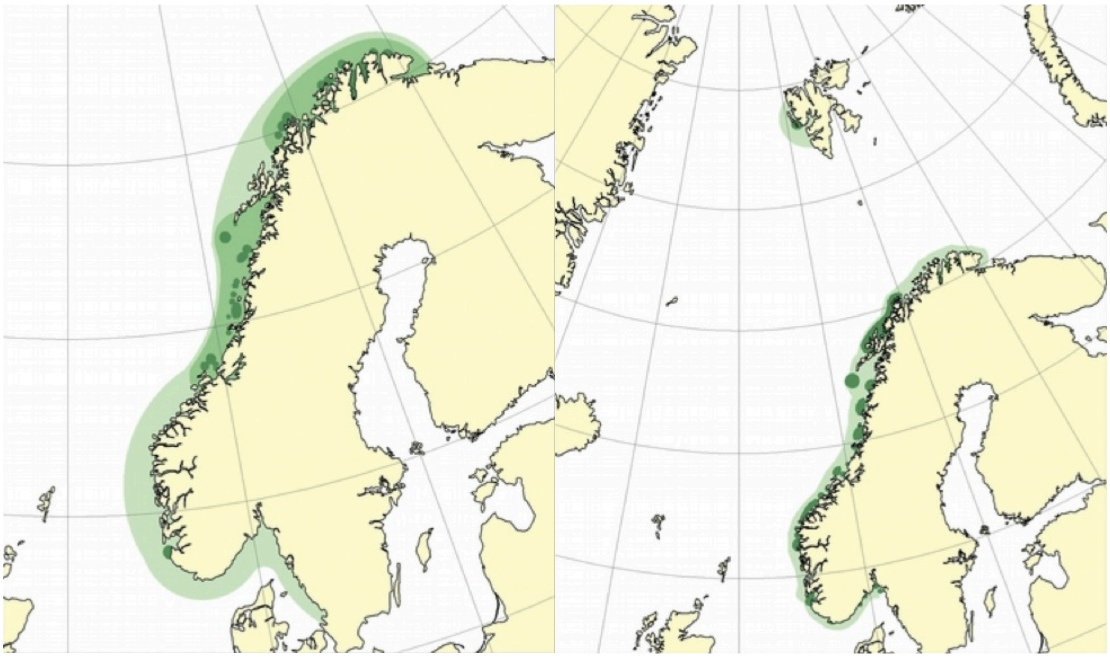


Figure 4.7: *Occurrence of Grey seal (left) and Harbour seal (right). Darker colour indicates an increase in concentration. Source: Institute of Marine Research.*

As mentioned above, whales dominate the marine mammals in terms of biomass. Some whale species feed in the Barents Sea and mate in more temperate areas, while other whale species spend all of the year in the Barents Sea. Most whale species are top predators, and feed on a wide range of the species in the Barents Sea.

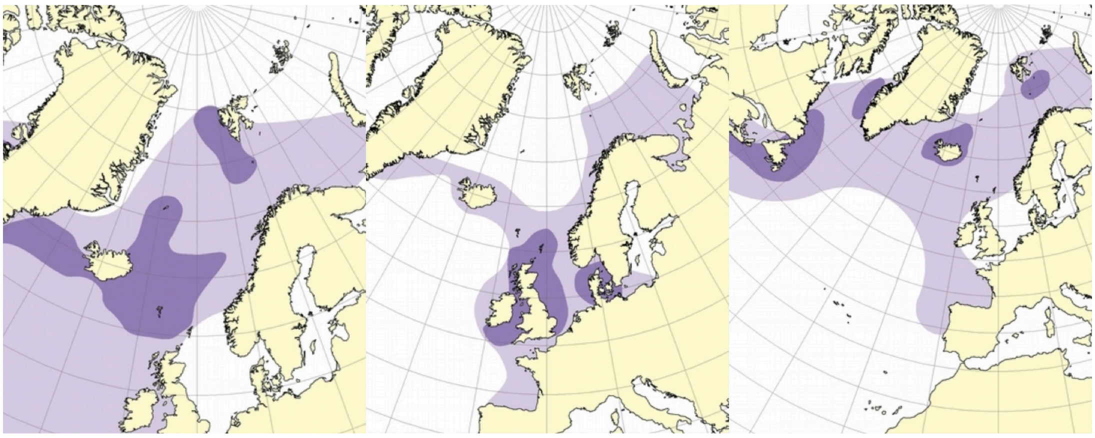


Figure 4.8: *Fin whale (left), Harbour Purpoise (middle) and Humpback whale (right). Darker colour indicates an increase in concentration of individuals. Source: Institute of Marine Research.*

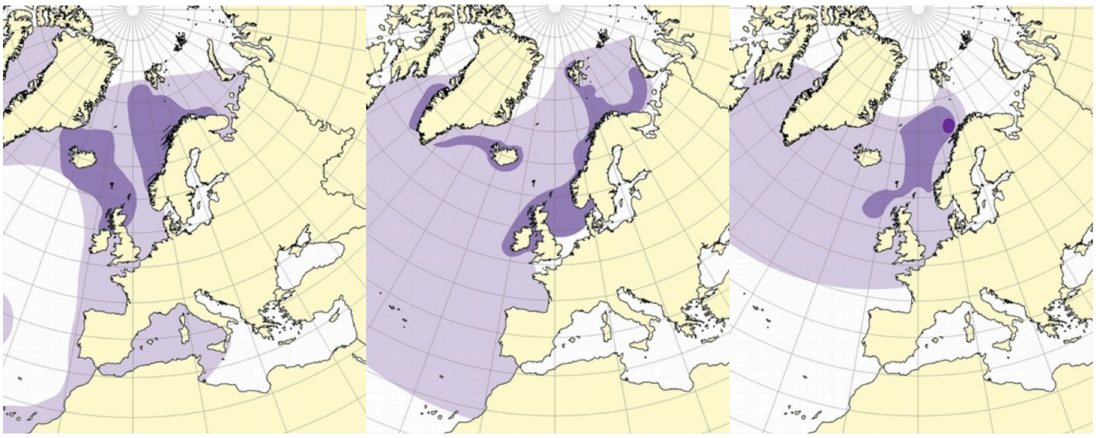


Figure 4.9: *Killer whale (left), Minke whale (middle) and Sperm whale (right). Darker colour indicates an increase in concentration of individuals. Source: Institute of Marine Research.*

4.2.3. Seabirds

The Barents Sea contains species of both national and international significance and is a globally important area for seabirds. The Barents Sea's nutritious nature, with large fish stocks and high production of plankton, contributes to good living conditions. It is estimated that the Barents Sea contains as many as 20 million individual seabirds during summer [31]. Capelin, Cod and Herring are important prey, where both grown individuals and the drifting larvae make for a nutritious source of food. Krill and amphipods are important sources of food for seabirds closer to the ice edge.

Little Auk, Northern Fulmar, Kittiwake, Common Guillemot, Puffin, Brünnich's Guillemot, Great Cormorant, Shag and Common eider are seabirds of particular interest in the Barents Sea.

The following figures illustrate the concentration of some of the pelagic seabirds in the Barents Sea, where a darker colour indicate an increase in concentration. The small dot in the centre of the images indicates the point of discharge used in the scenarios in this thesis. These figures are included to give an indication of the seabird concentration in the Barents Sea, and are not used to quantify the results. They are also used to give a rough indication of how the concentration of seabirds varies between the seasons.

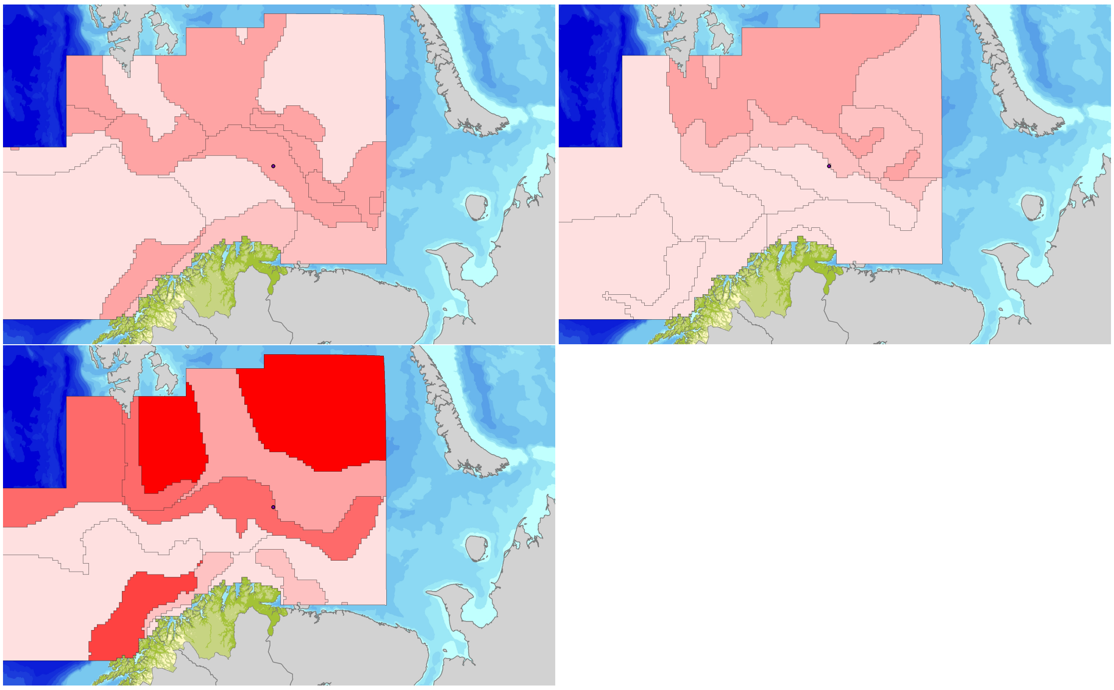


Figure 4.10: *Concentration of Little Auk during winter (upper left), spring/summer (upper right) and fall (lower). Source: NINA*

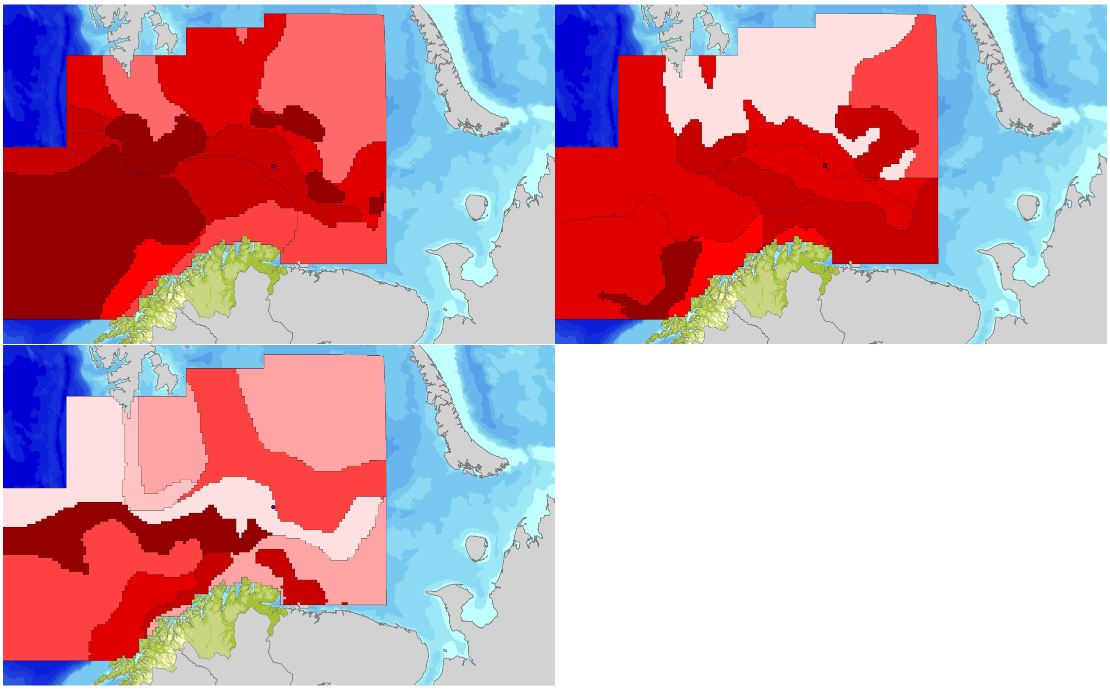


Figure 4.11: *Concentration of Northern Fulmar during winter (upper left), spring/summer (upper right) and fall (lower). Source: NINA*

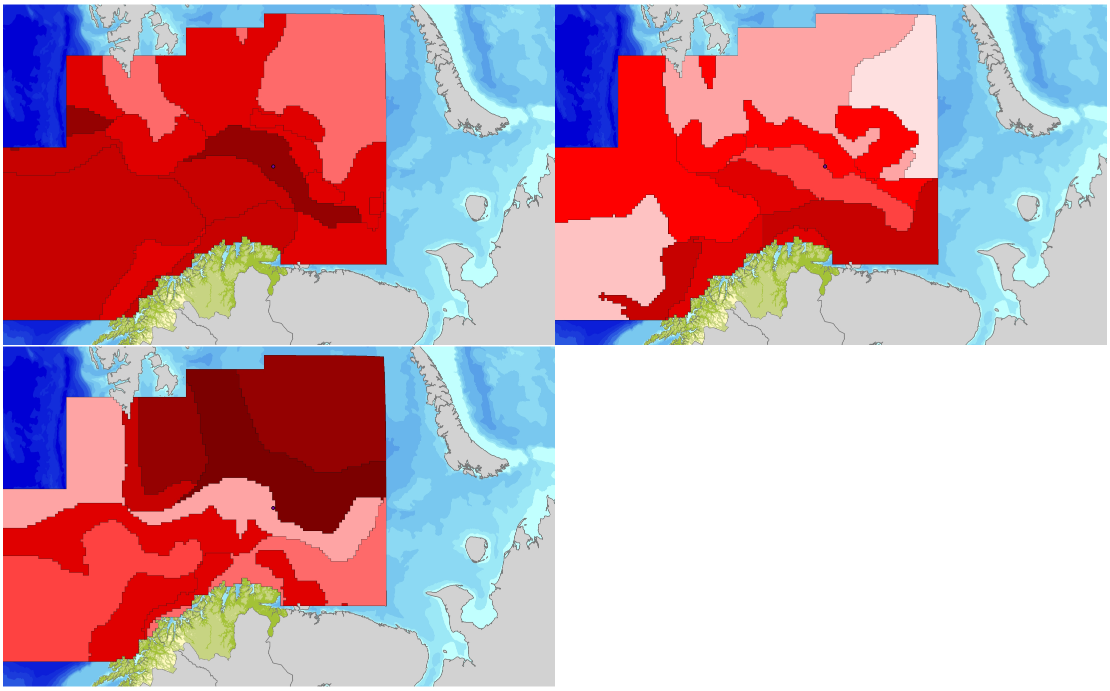


Figure 4.12: *Concentration of Kittiwake during winter (upper left), spring/summer (upper right) and fall (lower). Source: NINA*

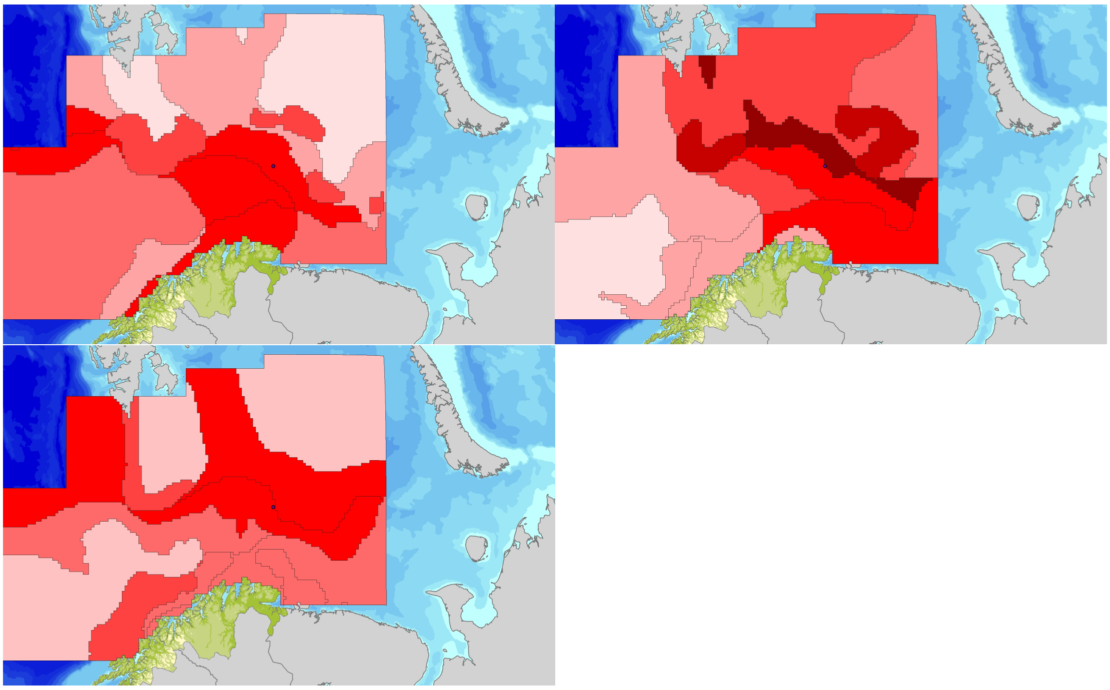


Figure 4.13: *Concentration of Common Guillemot during winter (upper left), spring/summer (upper right) and fall (lower). Source: NINA*

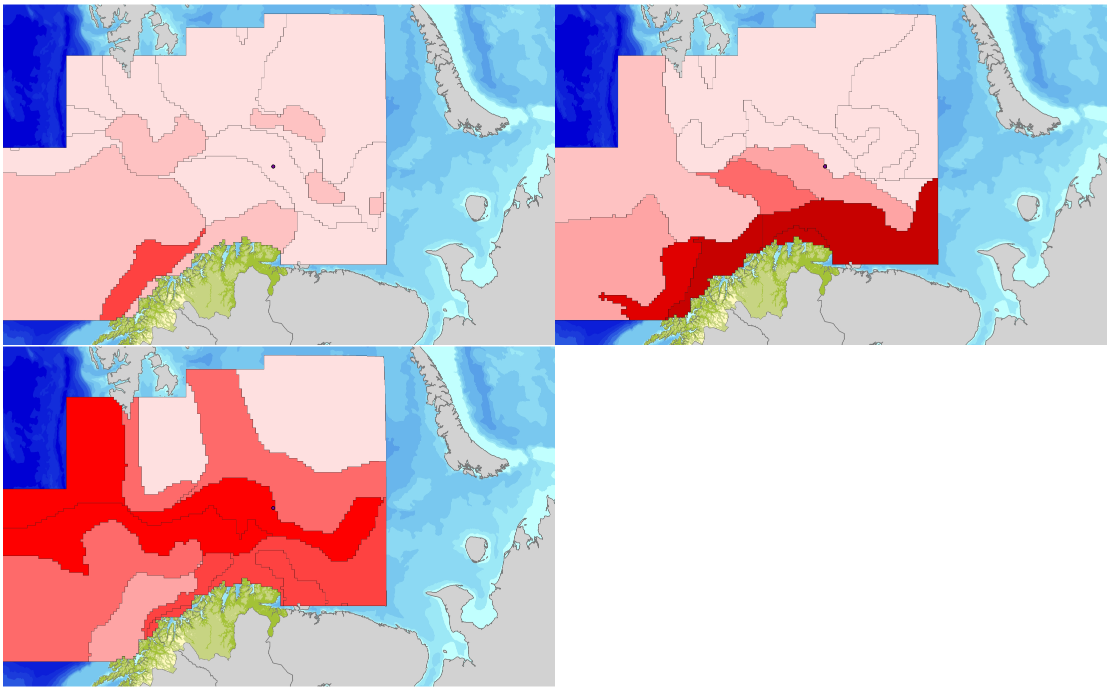


Figure 4.14: *Concentration of Puffin during winter (upper left), spring/summer (upper right) and fall (lower). Source: NINA*

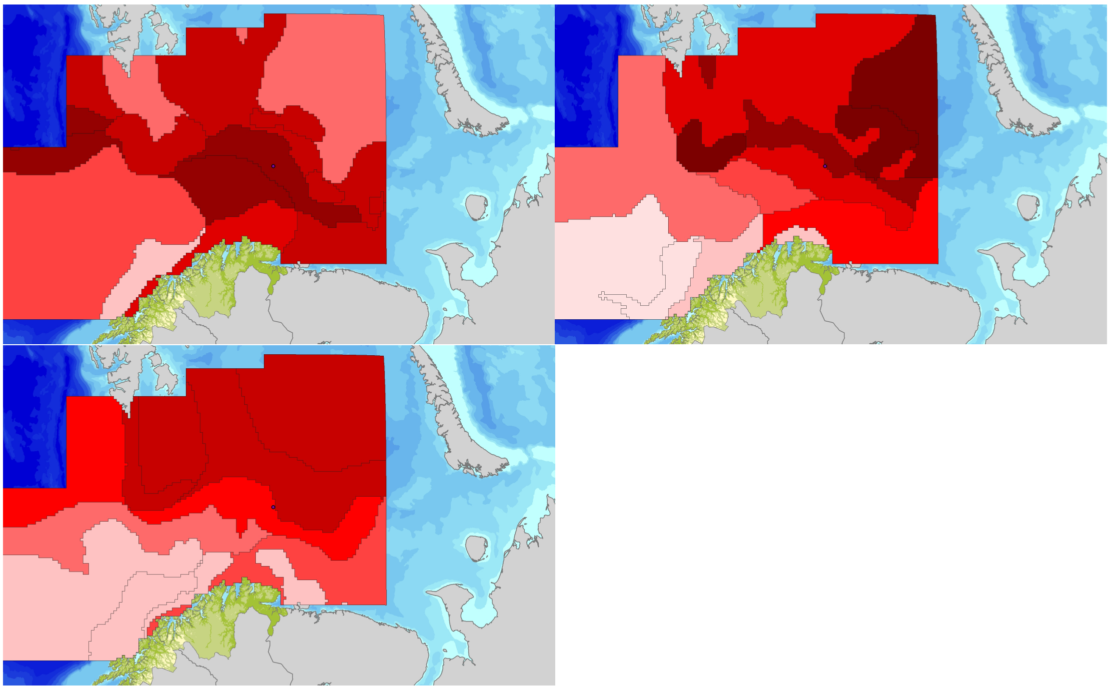


Figure 4.15: *Concentration of Brünnich's Guillemot during winter (upper left), spring/summer (upper right) and fall (lower). Source: NINA*

An oil slick on the sea surface might attract seabirds due to its calm appearance [32]. Seabirds that are contaminated by oil, either to a large or to a small extent, will loose the inherent isolating ability of their plumage. Depending on the amount of feathers covered with oil and the climatological factors, this will result in a lowering of the bird's body temperature to a possible lethal level. The bird may also ingest oil and be poisoned as it tries to clean its plumage. When affected by oil, the bird's ability to acquire food is also reduced, making it even more vulnerable. The low temperature in the Barents Sea makes seabirds particularly vulnerable towards oil spills during the winter.

A potential long-term effect of oil exposure to seabirds is poisoning through food. Seabirds are on a high level of the food chain, and toxins might accumulate through the lower levels of the food chain and appear as concentrated once it reaches the level of the seabirds.

The areas with high abundance of seabirds are often connected to oceanographic characteristics or seabed topography. Particularly, areas with high primary production attract pelagic seabirds. Areas with high primary production are often also high on zooplankton, crustacean and fish, all food sources for pelagic seabirds. In the Barents Sea, the polar front provides favourable conditions for primary production. Closer to the coastal zones of Norway, the convergence zone between the North Atlantic Current and the Norwegian Coastal Current creates an important feeding ground for seabirds. The fluctuating ice edge also provides favourable conditions for plankton, fish and seabirds further north.

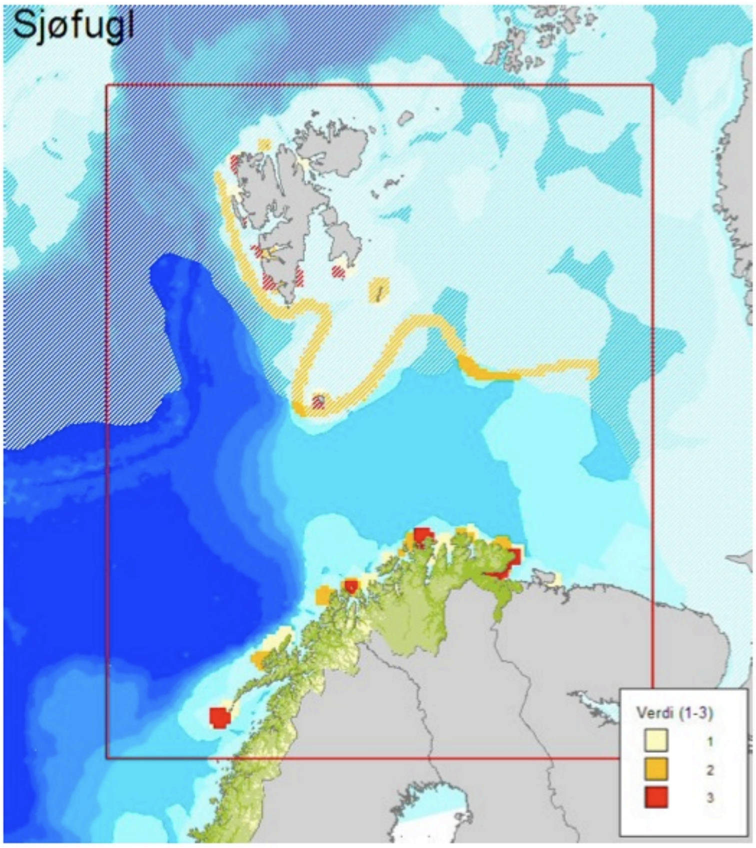


Figure 4.16: *Vulnerability chart for seabirds in the Norwegian part of the Barents Sea. Ref. Figure 2-3 from [33].*

The vulnerability of seabirds in the Norwegian part of the Barents Sea is described in Figure 4.16, where vulnerable areas are presented with grading from 1 to 3. The vulnerability criteria for seabirds are based on the report "especially environmentally sensitive areas (SMO) and the petroleum industry" presented in relation to the study of the consequences for the petroleum industry in the Lofoten- Barents Sea area (ULB). Description of vulnerability criteria in Figure 4.16 [33]:

- Grade 1: regional SMO + seabird colonies with > 25,000 individuals
- Grade 2: national SMO + seabird colonies with > 100,000 individuals + polar front
- Grade 3: international SMO + seabird colonies with > 300,000 individuals

4.2.4. Seasonal variations

A number of the seabirds living in the Barents Sea spend most of their life on the open ocean of the Barents Sea. This section gives a brief overview over the seasonal changes in the seabirds present in the Barents Sea.

The spring population of seabirds in the Barents Sea consists of birds migrating back to their breeding areas in the north and birds that have spent the winter in the area. This is quite similar to the state of the seabirds in the fall. As the ice opens up and retreats north the seabirds follow and gather in the breeding areas. Some of the seabirds are reliant on the ice retreating completely before the nesting can begin. If the breeding area still is connected to other areas by ice, both themselves and their offspring are exposed to predators such as the polar fox. The seabirds breeding season normally starts in April-May and lasts until July-August [30]. Some of the figures above (Figure 4.10 and Figure 4.12) indicate a lower concentration of seabirds on the open ocean during the spring and summer season than the other seasons.

The summer season in the Barents Sea contains the population that have nested, younger individuals and individuals that for some reason have not migrated to the breeding areas [30]. During the summer season, the Barents Sea also contains some stray species. Some seabird species moult after they are done breeding. The moulting period lasts for 3-7 weeks in July/August, and birds will during this period loose their ability to fly [30]. As they moult, they gather in colonies along the coast, and are in this period very vulnerable towards anthropogenic stress.

A significant southwest migration of seabird populations occurs during the fall. Seabirds in the Norwegian part of the Barents Sea migrates south to the Atlantic Ocean, and is being replaced by birds from the Russian part of the Barents Sea. Most of bird species migrates south during the fall, which characterizes the amount of seabirds in the Barents Sea in this period. The number of individual birds in the Barents Sea remains stable until October due to the late moulting by some species [30].

In the winter, sea ice forms in the north of the Barents Sea. The seabirds wintering in the Barents Sea are located from the ice edge to the coastal areas of Norway and Russia. Pelagic species often spend most of the winter season in this area.

4.3. Coastlines

4.3.1. Ice edge

The area close to the ice edge is a vulnerable area rich on life. As the ice melts during spring and summer, stable water masses offers excellent conditions for production of phytoplankton. Nutrients have accumulated during the winter, and as the ice melts and the sun input increases the primary production increases rapidly. Low water temperature assures that the amount of zooplankton is limited, thus reducing the feeding on phytoplankton. As melting of ice continues during the summer and the ice edge retreats north, the bloom of phytoplankton spreads throughout the Barents Sea.

Phytoplankton is microscopic algae that utilises energy from the sun to produce organic compounds from inorganic compounds. The organic compounds produced are the basic nutrition for all organisms in the sea. The ice edge is considered to be of great significance when assessing impact of an oil spill on the marine arctic environment.

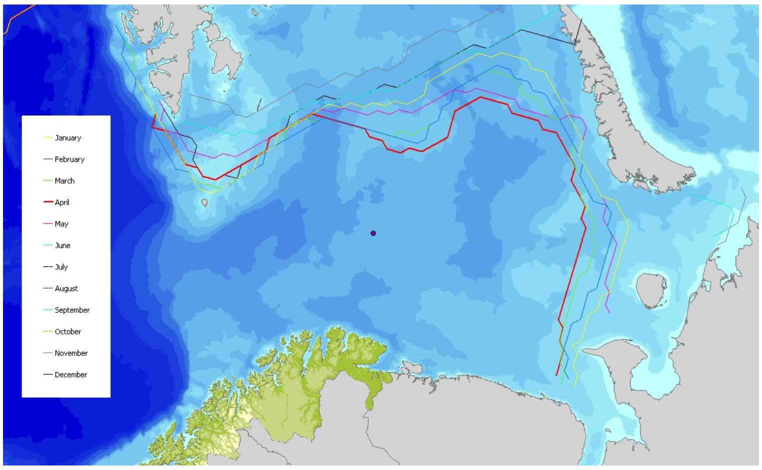


Figure 4.17: *Median extent of sea ice by month. Data from 1979 to 2000. Circle in the centre of the figure indicates the source of the oil spill. Source: National Snow and Ice Data Center (NSIDC).*

4.3.2. Norwegian coast

The coastal habitat is generally considered to be vulnerable towards oil pollution. The coastal areas contain important breeding areas for seabirds, spawning areas for fish and moulting areas for marine mammals. This is illustrated in the vulnerability charts for the coastal area presented below.

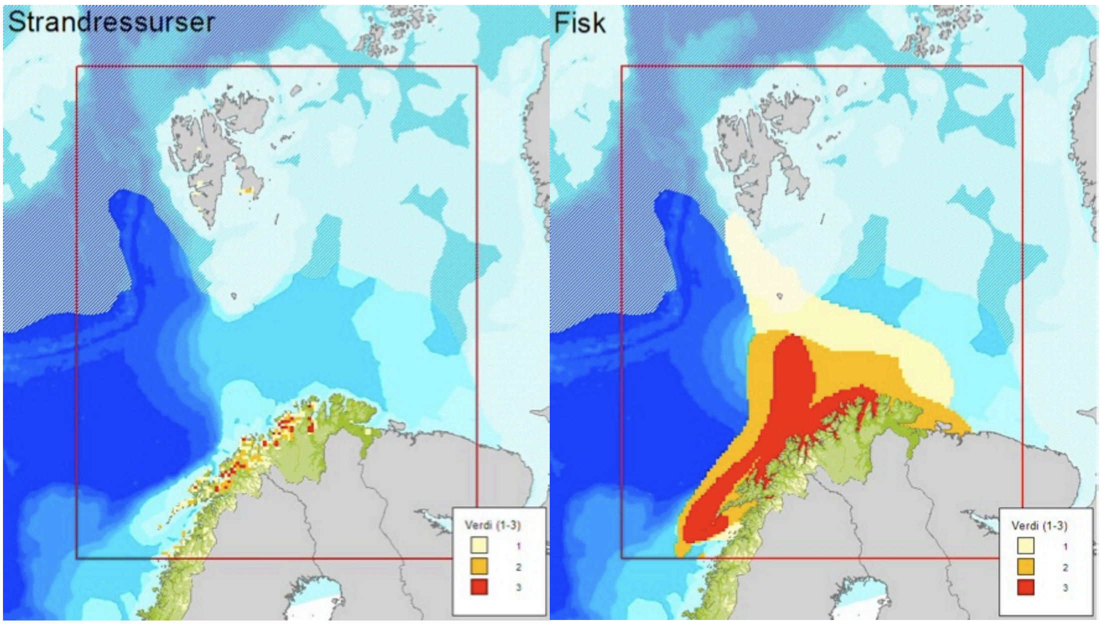


Figure 4.18: Vulnerability chart for coastal resources (left) and fish eggs and larvae (right). Source: DNV, Figure 2-2 and Figure 2-5 from [33].

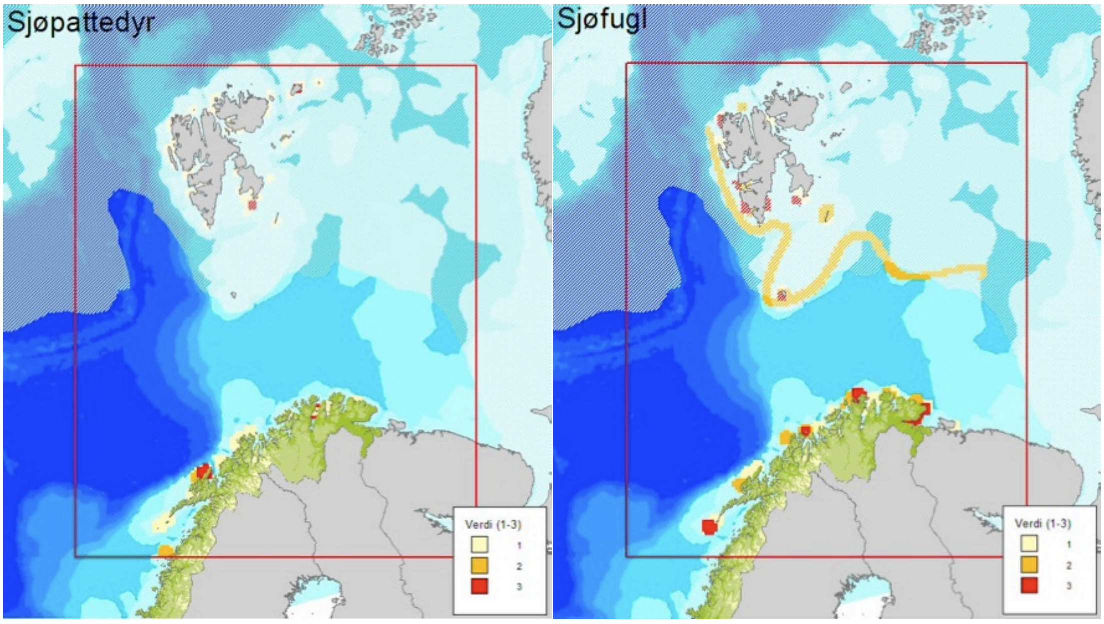


Figure 4.19: *Vulnerability chart for marine mammals (left) and seabirds (right). Source: DNV, Figure 2-4 and 2-3 from [33].*

5. Results

Oil drift statistics were generated and presented with a 10 by 10 km grid cell resolution, as suggested by NOFO. The figures below illustrate the area on the surface of the ocean that is affected by an oil spill, and not the amount of oil in the water column or on the sea bottom. It is chosen to illustrate the surface affected because it is believed to be the compartment with the highest potential for environmental impact.

Each of the impacted 10 by 10 km grid cells are assigned a colour to indicate the probability of a single oil spill to reach the cell. The probability increases as the colour goes from yellow to red. The colours associated with the respective probability ranges are presented in Figure 5.1.

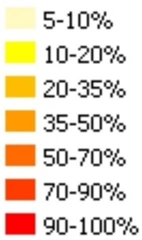


Figure 5.1: *Colour of cells and probability for a single oil spill to impact the cell.*

5.1. Weighted scenarios

Topside and subsea blowout are presented for each of the four seasons; spring (March-May), summer (June-August), autumn (September-November) and winter (December-February). These scenarios are weighted. This means that the model considers the probability for having each of the rates and durations, giving a representative area of impact compared to worst-case scenarios where probability of rate and duration is not considered.

Keep in mind that these graphics does not reflect the extent of one single oil spill, but the area that is affected in more than 5% of single scenarios (influence area) based on statistics from 3600 simulations in each season. The influenced area differs slightly between the seasons due to seasonal variations in prevailing wind and water currents and variations in stratification of the water column.

5.1.1. Spring (March-May)

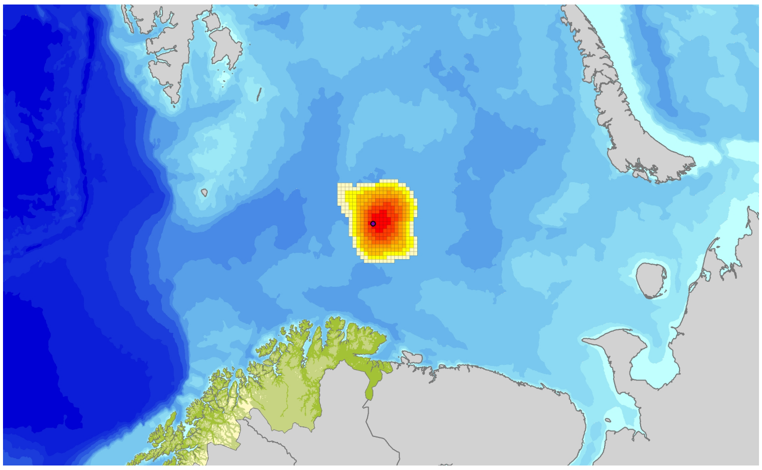


Figure 5.2: *Weighted topside scenario for spring. Note that the figure indicates the statistical influence area in the given season, and not the spreading of an oil slick from one scenario or discharge.*

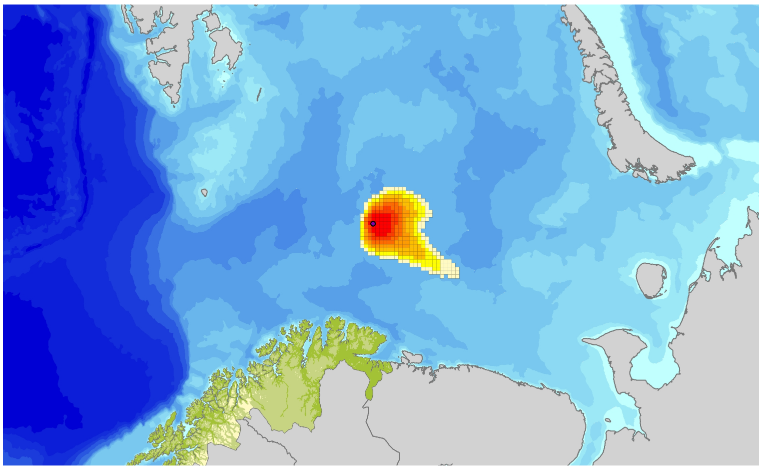


Figure 5.3: *Weighted subsea scenario for spring. Note that the figure indicates the statistical influence area in the given season, and not the spreading of an oil slick from one scenario or discharge.*

5.1.2. Summer (June-August)

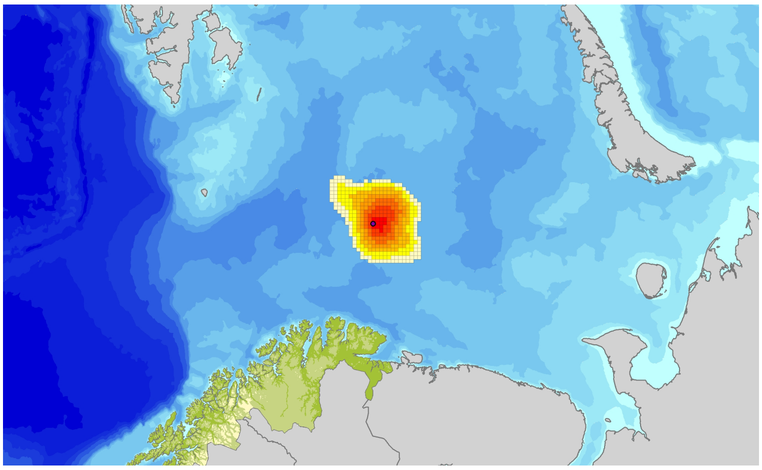


Figure 5.4: *Weighted topside scenario for summer. Note that the figure indicates the statistical influence area in the given season, and <u>not</u> the spreading of an oil slick from one scenario or discharge.*

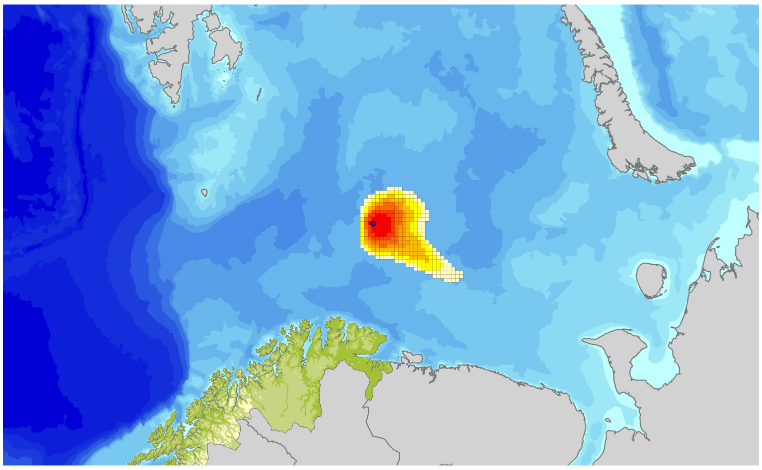


Figure 5.5: *Weighted subsea scenario for summer. Note that the figure indicates the statistical influence area in the given season, and <u>not</u> the spreading of an oil slick from one scenario or discharge.*

5.1.3. Autumn (September-November)

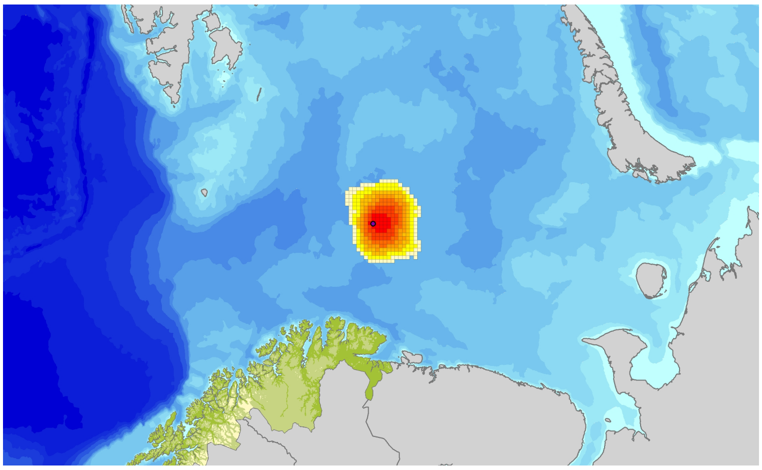


Figure 5.6: *Weighted topside scenario for autumn. Note that the figure indicates the statistical influence area in the given season, and* *<u>not</u>* *the spreading of an oil slick from one scenario or discharge.*

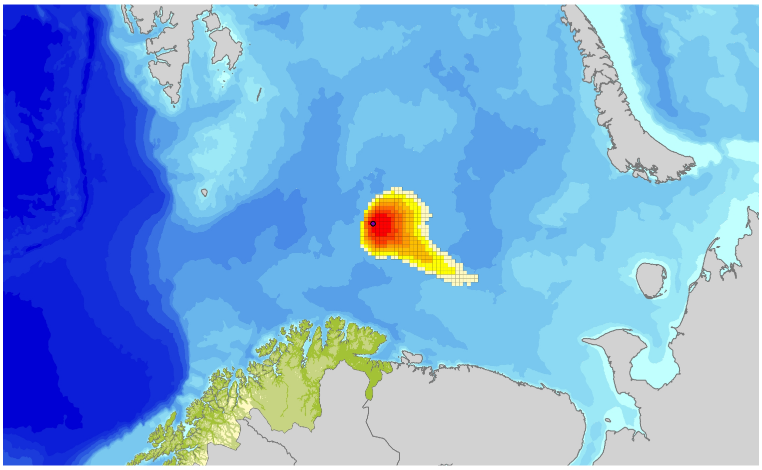


Figure 5.7: *Weighted subsea scenario for autumn. Note that the figure indicates the statistical influence area in the given season, and* *<u>not</u>* *the spreading of an oil slick from one scenario or discharge.*

5.1.4. Winter (December-February)

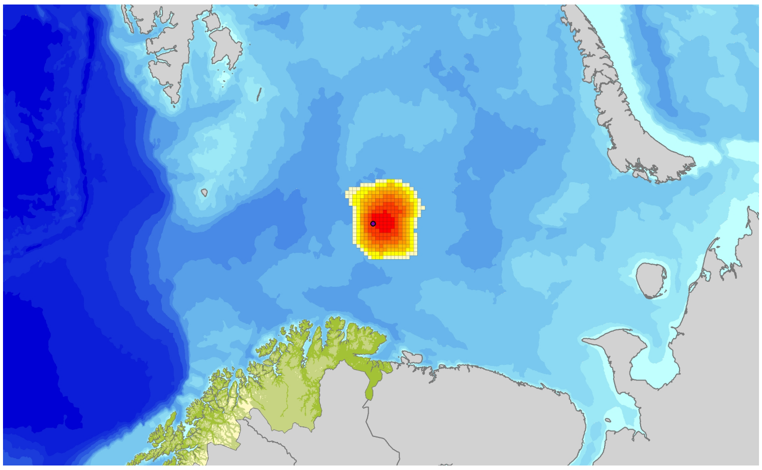


Figure 5.8: *Weighted topside scenario for winter. Note that the figure indicates the statistical influence area in the given season, and <u>not</u> the spreading of an oil slick from one scenario or discharge.*

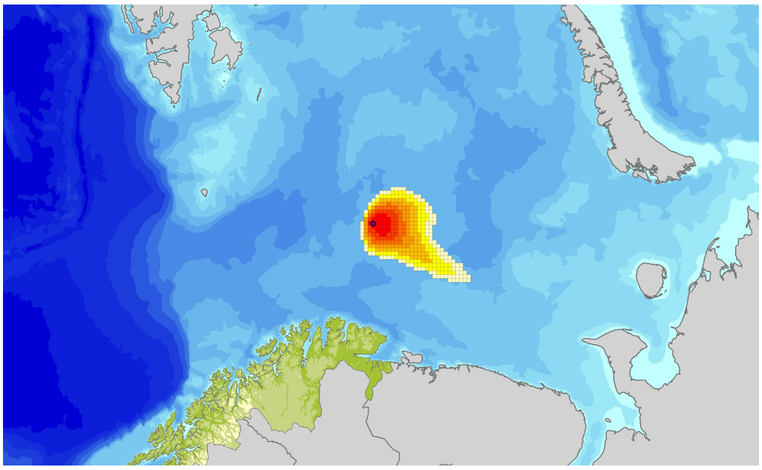


Figure 5.9: *Weighted subsea scenario for winter. Note that the figure indicates the statistical influence area in the given season, and <u>not</u> the spreading of an oil slick from one scenario or discharge.*

5.2. Long-term blowout scenarios

The long-term blowout scenarios are included to illustrate the extent of a long-term blowout, in disregard of the actual probability of the duration.

Keep in mind that these graphics does not reflect the extent of one single oil spill, but the area that is affected in more than 5% of single scenarios based on year-round data from 3600 simulations.

5.2.1. 35 days duration

The following two figures illustrate the extent of a subsea blowout with duration of 35 days, given two different blowout rates.

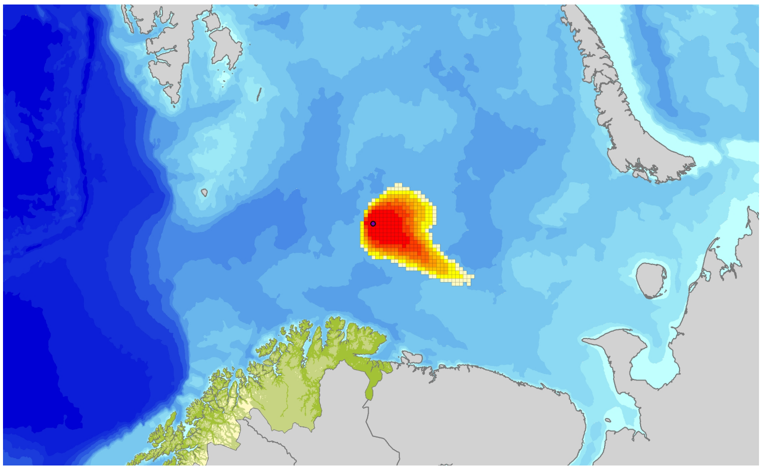


Figure 5.10: *Subsea blowout with a rate of 3666 Sm^3/day for 35 days. Note that the figure indicates the statistical influence area based on year-round data, and* <u>*not*</u> *the spreading of an oil slick from one discharge.*

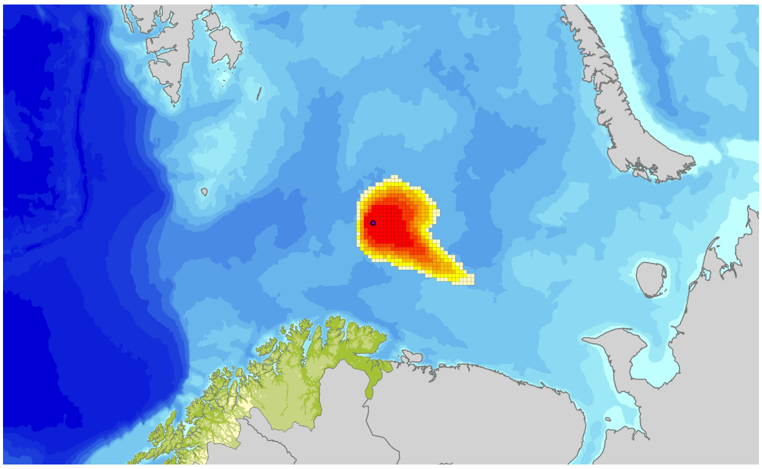


Figure 5.11: *Subsea blowout with a rate of 4810 Sm^3/day for 35 days. Note that the figure indicates the statistical influence area based on year-round data, and* <u>*not*</u> *the spreading of an oil slick from one discharge.*

5.2.2. 100 days duration

These figures illustrate the same rates as in 5.2.1, but the duration is here extended to 100 days. The 10 by 10 km grid cells limits the model output in the eastward direction, and graphic figures can only indicate oil within the area shown in Figure 3.6. This is the reason why the oil drift graphics appears to have been cut as it reaches a certain longitude.

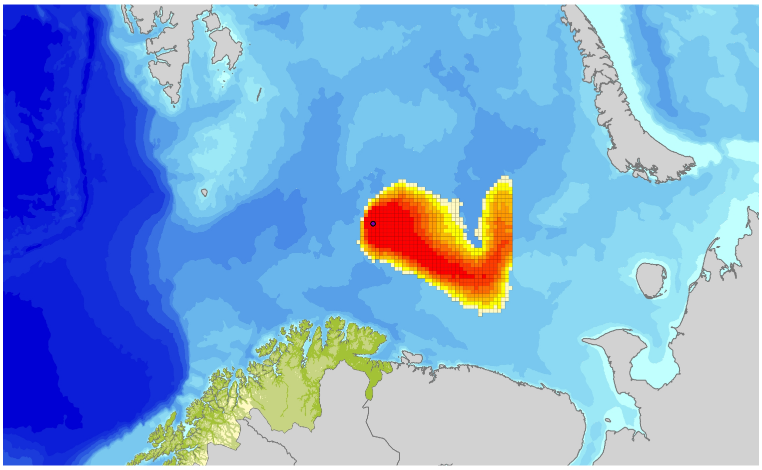


Figure 5.12: *Subsea blowout with a rate of 2412 Sm³/day for 100 days. Note that the figure indicates the statistical influence area based on year-round data, and <u>not</u> the spreading of an oil slick from one discharge.*

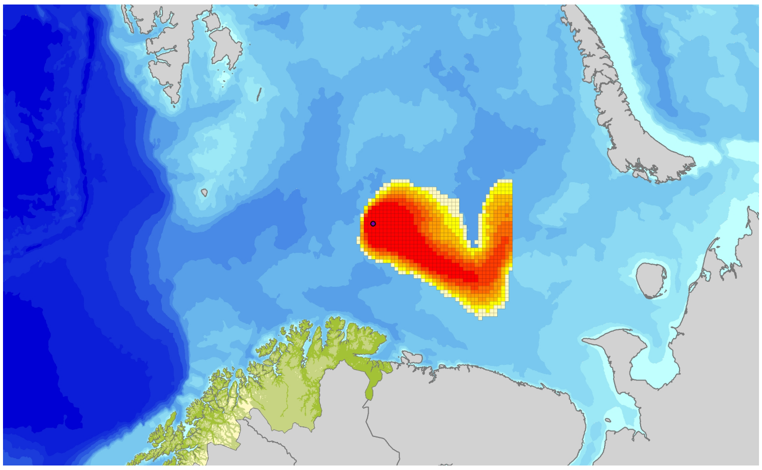


Figure 5.13: *Subsea blowout with a rate of 3666 Sm³/day for 100 days. Note that the figure indicates the statistical influence area based on year-round data, and <u>not</u> the spreading of an oil slick from one discharge.*

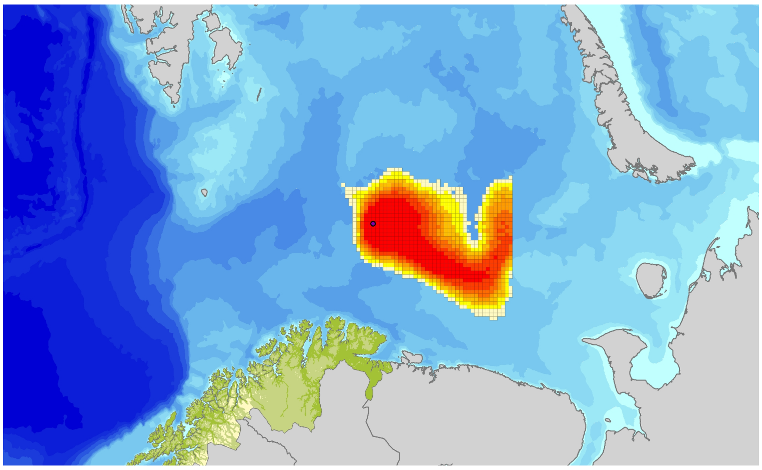


Figure 5.14: *Subsea blowout with a rate of 4810 Sm³/day for 100 days. Note that the figure indicates the statistical influence area based on year-round data, and not the spreading of an oil slick from one discharge.*

6. Discussion

6.1. Impact on ecosystem components

The results imply that an oil spill in this area will overlap with grounds important for fish, seabirds and marine mammals on the open ocean. The size of the oil spill will be decisive for the number of individuals and species affected.

However, the scenarios also indicate that in the case of a blowout at the chosen location, there is zero probability for oil to reach the coastlines of Norway and Russia. Even under the worst-case scenario, where the duration is 100 days and rate is 4810 Sm^3/day, the oil is not reaching vulnerable coastal areas (Figure 5.14). This means that particularly vulnerable areas, such as breeding, growth and moulting areas along the coast is left unaffected by the oil spill on the open ocean.

The impact on chosen components of the Barents Sea ecosystem is discussed below. This thesis chooses not to consider impact on flora and fauna on the seabed. This is excluded due to the limitations of the thesis (Chapter 1.3), and based on the assumption that impact on components in the water column and on the sea surface will contribute more to the overall environmental risk in this area compared to those on the seabed. Oil from a blowout is likely to affect benthos close to the source. As the oil rises to the sea surface relatively fast, the area on the seabed affected by the oil is assumed to be limited. Oil also has the ability to settle on the seabed at a later point as a result of weathering processes, where it may impact marine life.

6.1.1. Ice edge

There is no overlap between the statistical extent of the ice edge presented in chapter 4.3.1 and the oil spill scenarios considered in this thesis. Even under worst-case conditions, which itself is highly unlikely, oil is unlikely to impact the ice edge to the north or to the east. The environmental impact of an oil spill on the ice edge will not be discussed further.

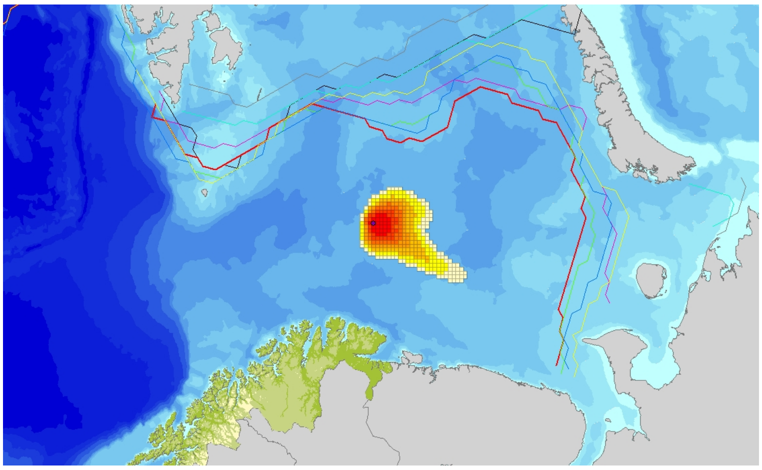


Figure 6.1: *Weighted oil spill scenario for all four seasons and statistical extent of the ice edge.*

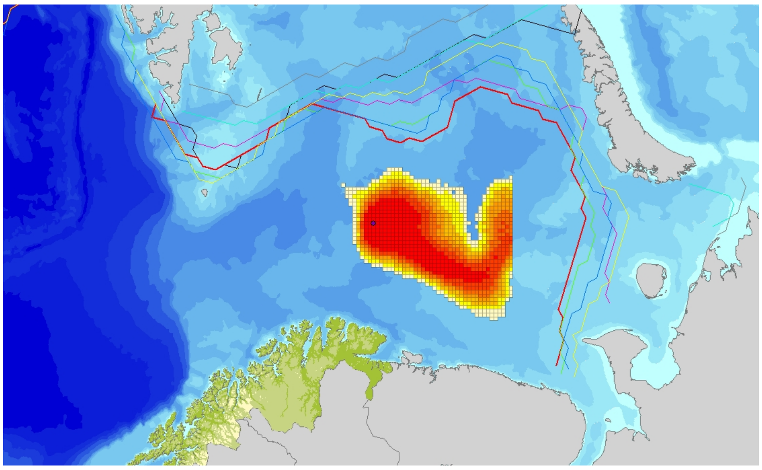


Figure 6.2: *The worst-case scenario considered in this thesis and the statistical extent of the ice edge.*

However, if the prospect of interest were located about 60-80 km further north or east, and the blowout occurred in April, the probability of having oil impacting the ice would be significantly increased.

6.1.2. Coastlines

Oil from the scenarios considered in this thesis has a very low probability of reaching the coastlines of Norway and Russia, and consequences associated with coastal impact are thus not discussed further.

If the prospect of interest were located approximately 100 km closer to the Norwegian coastline, the probability for oil reaching the coast of Norway and Russia would have been significantly increased. This applies if the worst-case scenarios are considered. For the weighted scenarios to impact the coastal ecosystem, the prospect where the blowout occurs has to be "moved" even further towards the coast.

6.1.3. Fish

Fish populations are not likely to be significantly affected by an oil spill produced by the scenarios considered in this thesis. It is reasonable to believe that the majority of grown individuals are able to navigate away from a heavy oil-polluted area [29], and impact can thus be assumed to be limited to those individuals that for some reason are unable to navigate away from the polluted site.

Drifting larvae and fry are more likely to be affected by oil pollution, as they may be unable to avoid the oil-polluted areas. Oil exposure towards larvae or fry might lead to deformation or death [12, 32]. The spawning areas for species living in the Barents Sea are primarily located in coastal areas in the southern Barents Sea and the northern Norwegian Sea (Figure 4.1, Figure 4.3 and Figure 4.5). The impact on spawn and larvae is a subject of study and is of great relevance when it comes to documenting environmental impact of oil on spawning areas outside Vesterålen and Lofoten. Studies on the subject are carried out as the opening process concerning Vesterålen and Lofoten are progressing, and recent studies suggests that impact on fish spawn and consequently fish populations are not as extensive as earlier suggested [12]. In addition, as these areas are located far from the centre of the blowout in this thesis, the probability for an oil spill to affect the spawning is considered to be very low. Drifting larvae and spawn might be affected if they are located in the area close to the blowout. However, as the damage in our case is limited to the individuals located at the given area that is not able to navigate away, the effects are likely not to go beyond the individual level.

Fish stocks are generally considered to be quite robust. The biomass of the North-East Arctic Cod stock was in 2010 1,140,000 tonnes [29]. In the following year of 2011, the fishing quota set for this stock was 319,000 tonnes [29]. This implies that fisheries are able to take out about 28% of the stock and still keep it at a healthy level. This reasoning suggests that consequences of a long-term oil spill in this area will result in severe economic loss for the fishing industry in order to compensate for the decrease in fish stocks until the stocks regain their health. However, a more severe situation will appear if an oil spill occur immediately after the fishing industry have harvested 28% of the stock. This will cause the stock to be further decreased, and longer time have to be allowed before the stock is able to regain its health.

Fish matures fairly fast, and when they spawn they produce millions of eggs each of which not all grow up to be an addition to the stock [34]. The number of eggs and larvae that lives to be an addition to the stock varies from year to year as a result of several factors [34]. This variation can be large, and the addition to the cod stock has proven to be 20 times higher in years with high survival rate compared to years with low survival rate [34]. Studies show that the most probable impact of an oil spill on spawning areas will have relatively low consequences [12], and combined with the roughness of the fish stock and the natural variations in the success rate of spawning it can be assumed that consequences of an oil spill towards the fish stocks in the area are very low.

6.1.4. Marine mammals

Marine mammals also have the ability to avoid areas polluted by oil on the open ocean. The marine mammals are most vulnerable when they gather in large groups in coastal areas to mate, moult and rest. The scenarios assessed in this thesis indicate that there is no probability for the oil to reach the ice edge, the Norwegian coastline or the Russian coastline. Due to this oil drift pattern, damage to marine mammals is likely to be limited to an individual level rather than a population level.

It is generally more difficult to do research on impact of oil on marine mammals than on i.e. fish. The marine mammals have long lifespans and produce few offspring each breeding period, and are thus unfit to "produce" for research. They are also large in size and require vast water habitats in order to live a normal life. For these reasons there are less data available on the impact of oil on marine mammals. The long lifespan of marine mammals also indicates that they as populations have long restitution time. This marks them as generally vulnerable towards external stress, and an oil spill that affects breeding, moulting and resting area along the coast will potentially have severe consequences for marine mammals beyond the individual level.

6.1.5. Seabirds

Seabirds are very vulnerable towards oil spills both on the open ocean and in coastal areas. Pelagic seabirds may be attracted by the calm surface created by an oil slick on the open ocean as a place to rest and feed [32]. As mentioned in chapter 4.2.3, seabirds are reliant on their plumage for buoyancy and insulation. Seabirds loose both buoyancy and insulation as soon as their feathers get oiled. This is likely to have a lethal effect on the oiled bird, either through freezing, starving due to reduced ability to acquire food or through poisoning [35]. Any oil spill in this area will affect seabirds and very possibly lead to the death of many. The size of an oil spill will be decisive for the number of individuals affected. All the scenarios considered in this thesis is likely to induce an oil covered surface area that will affect a number of the seabird species that is considered to be among the most vulnerable in the Barents Sea.

Seabirds mature late, are long lived and produce few eggs in each breeding season compared to i.e. fish. Their ability to adapt to changes is lower, and due to the low reproduction rate the seabird populations have longer restitution time than many other ecosystem components in the Barents Sea. The long restitution time of seabird populations contributes to a higher vulnerability towards anthropogenic impact. Seabirds are in this thesis considered to be the most vulnerable ecosystem component in the area. This have resulted in a focus on surface spreading of oil rather than water column spreading, as this is considered to contribute more to the overall environmental risk in the area.

An accidental oil spill in this area is highly unlikely to result in impact on coastal areas important for seabirds, as the prospect where the blowout occurs is located quite far off shore. Given this finding, it is not unreasonable to argue that a blowout might have lower environmental consequences if it occurs in the breeding season due to the amount of birds located at the unaffected nesting areas along the coast in this period. This is somewhat contradictory to the belief that the breeding season is the most vulnerable season when considering oil spills in the Barents Sea. The breeding season probably still is the most vulnerable towards oil impact, but if the blowout is located at a sufficient distance offshore, the breeding season might prove to be the season where the environmental impact toward seabirds is at its lowest.

6.2. Effect of input parameters to the overall environmental risk

There are basically four important inputs to the oil drift model used in this thesis. These are rate, duration, oil type and location. Each of these will have a significant impact on the output from the model, and will affect the overall environmental risk posed by the scenario.

Location is a very important parameter. Location will determine the distance from vulnerable resources, prevailing direction of oil drift, complexity of oil response and recovery and to some degree speed of natural weathering. The distance from vulnerable resources and VECs is of great importance when assessing environmental risk. The distance from the epicentre of the blowout scenarios considered in this thesis to the Norwegian shoreline is approximately 258 km. This is considered to be quite far off shore.

The rate and duration of a blowout will have a severe impact on the overall environmental risk. A blowout is statistically most likely to have a short duration (<5 days) [36]. The long-term blowout and worst-case scenarios presented in this thesis is only probable if well intervention (capping) and drilling of relief well is unsuccessful, which is considered to be unlikely. From the results of the long-term blowout simulations presented above, one can argue that duration has a greater impact on the overall environmental risk than rate. The extent of the oil impacted surface area appears approximately similar for blowouts of the same duration but with different rates (Figure 5.12, Figure 5.13 and Figure 5.14).

The characteristics of oil from fields on the Norwegian continental shelf vary greatly. Light oils will evaporate faster than heavy oils, but might during their short life span on the open ocean cover a greater area. The choice of oil type has a great impact on the outcome of the oil drift modelling. This thesis uses the Realgrunnen crude oil from the Goliat development in the south of the Barents Sea. The Realgrunnen crude oil is characterized as naphthenic, with properties similar to both paraffinic and waxy crude oils [23]. This oil type was chosen due to the excessive amount of information available concerning the characteristics of this oil type. This oil type has also become somewhat of an "industry standard" to use when it comes to oil drift modelling in the Barents Sea. This is likely to change when more prospects are explored and the development interest in the area increases.

6.3. The "Macondo accident of the northern seas"

Can we get a blowout similar to the Macondo-accident in this part of the Barents Sea? This question was raised during the planning phase of this thesis, and it is still a hard question to answer. However, after working on this thesis, some factors have emerged that helps answering this question.

The Macondo accident is the largest accident in the history of offshore oil and gas production [17]. It is still discussed whether it is the worst, but it is definitely the largest when it comes to volume discharged. From an environmental point of view, an oil accident has to result in an environmental impact of the same magnitude as the Macondo accident in order for the accident to be as severe. This implies that if the vulnerability in an area is considered to be higher than in the Gulf of Mexico, a lower amount of oil is needed in the environment in order to reach the same magnitude of environmental impact as the Macondo accident.

Based on this reasoning, one cannot with 100% certainty guarantee that an accident of the same magnitude as the Macondo accident cannot happen in this area of the Barents Sea. However, there are some important factors that argue against this statement. There is yet to discover prospects with high temperature and high pressure in this part of the Barents Sea. This is a key point in arguing against the "Macondo accident of the northern seas". The geological history of the area suggests a recent uplift that would result in a decrease in both pressure and temperature in the geological structures in the area [17, 37]. The lower pressure makes it easier to do well intervention and to stop a blowout with capping, thus reducing the risk the well poses to the workers and the environment. Environmental conditions that argue for an increased probability of the Macondo accident of the northern seas is discussed further in section 6.5.

6.4. Limitations to the model

As illustrated in Figure 3.6, the grid used in the illustration of OS3D results does not cover the entire Barents Sea. The grid reaches into the Russian part of the Barents Sea, but does not extend sufficiently to illustrate the worst case scenarios modelled at the chosen location. This results in unclear illustration of oil drift east of the predefined grid. As the exploration of oil and gas extends to the easternmost areas of the Norwegian part of the Barents Sea, the predefined grid have to be extended further east, or the method for reporting oil drift have to be altered.

The output from OS3D is presented for 10x10 km grids on the Norwegian continental shelf. As oil drift simulations are prepared for areas with high concentration of vulnerable resources, such as seabird breeding areas along the coast, it might be beneficial to increase the resolution of the output. An increased resolution is likely to result in a more detailed picture on what coastal areas are statistically likely to be affected.

6.5. Uncertainty

The area in general was chosen based on the increasing interest for opening of the area to petroleum exploration and development. After the Russian Duma ratified the treaty concerning maritime delimitation of the Barents Sea between Norway and Russia in the end of March 2011, the interest in the area was confirmed. The exact coordination of the oil spill source used in this thesis is to some degree based upon seismic surveys carried out by the U.S.S.R in the 1970s. It should be noted that these surveys are associated with a great deal of uncertainty. The 2D seismic technology used in the period is less sophisticated than the technology available today. In this period, the political situation was also tenser than it is today and it is not unreasonable to believe that this could have affected the results of the seismic surveys. It is thus emphasised that the seismic surveys are not used as a basis for the choice of area, but rather as an indication that the area is interesting when it comes to oil and gas exploration. It is also worth mentioning that, due to the fact that this is a case study, the actual presence of oil at the chosen location is not decisive for the results of this thesis.

There is always uncertainty associated with the rate of an accidental blowout. When estimating the rate prior to an environmental risk analysis, a detailed well risk analysis is carried out for the purpose of decision support and to establish a more realistic rate probability distribution. The rates used as input to the modelling in this thesis is solely based on the rates present in environmental risk analysis for other exploratory wells in the Barents Sea (see Appendix I). The rates from fields presented in Appendix I was grouped according to the desired input of the model, and was compared to generic rates (presented in Table 3.4) for the entire Norwegian continental shelf to affirm their validity. This implies that the scenarios used in this thesis have rates that comply with the rest of the Barents Sea. This is reasonable to assume for this thesis due to limitations and simplifications made, but might not be the case for an actual field in the area.

There is also uncertainty associated with the duration of an accidental blowout. The longest duration considered in this thesis is 100 days. In order for a blowout to have duration of 100 days, the well should have relatively high pressure and good flow characteristics and the work with interfering with or stopping the well stream have to be disrupted in some way. As mentioned in paragraph 3.4.2, statistics suggests that 77% of blowouts are terminated due to bridging. In the same paragraph it is suggested that due to the geological history of the area, the percentage have been reduced slightly. However, it is difficult to estimate the probability of bridging without an actual well to study, as this to a great extent is based upon well specific parameters and reservoir characteristics. Assuming lower pressure and temperature in the reservoirs present in the Barents Sea compared to the Gulf of Mexico, it can be argued that the probability of successfully capping a well is higher. This indicates that the probability of having duration of 100 days is very low. However, the Barents Sea offers some challenging weather conditions that were not present in the Gulf of Mexico during the Macondo accident. If a blowout occurs in the Barents Sea during the winter season, operating conditions for personnel aboard rigs and ships may be extreme. Extreme conditions may also occur in the Gulf of Mexico, but personnel in the Barents Sea may be forced to operate in conditions with icing on ships and structures, temperatures below zero centigrade and no sunlight input throughout the day. With this in mind, one cannot say that a blowout in the Barents Sea impossibly can have duration of 100 days.

As it is impossible to know the oil type located in the area of interest, the oil type from the Goliat field has been used throughout this thesis. This choice was made deliberately due to the excessive amount of knowledge available associated with this oil type compared to other types in the region. If oil is found in the area, and the oil type differs from the type found at the Goliat field, the differences in model output will depend on the differences in the composition of the new oil type versus the composition of the Goliat oil.

6.6. Conservative approach

A small discussion about the effects of conservative choices is worth including in this final part of the thesis. Throughout the process of establishing data input to the oil drift model, a number of decisions are made. One thing that most of these decisions have in common is that they are made conservatively. When these conservative data are combined in the oil drift model, the conservative choices may be amplified.

The conservative approach during the early decision-making process will probably result in the output from the model not being accurate compared to an actual blowout event. The output from the oil drift model is likely to illustrate more severe consequences compared to an accidental blowout under real circumstances. As the output is often used to dimension the need for oil spill preparedness equipment, the conservative choices made in initial stages of the modelling will most likely contribute to an over-dimensioning of oil spill preparedness.

7. Conclusion

The aim of this study was to highlight the environmental consequences associated with a blowout of oil in the former disputed area between Norway and Russia in the Barents Sea, to discuss the probability for having an accident in the Barents Sea that can be compared in terms of magnitude to the Macondo accident in the Gulf of Mexico during spring and summer of 2010 and to assess whether tools and models used for analysing environmental risk on the Norwegian continental shelf are sufficient to highlight the risk realistically.

From the results of the study, the following conclusions can be drawn:

- A blowout of oil at the location chosen in this study seems highly unlikely to result in oil impact on vulnerable areas along the coastlines of Norway and Russia in the Barents Sea, and also seems highly unlikely to impact the vulnerable ice edge to the north and to the east even under worst-case scenarios.
- Fish and marine mammals are likely only to be affected on an individual level, indicating that an oil spill at the location chosen in this thesis will pose a minimal threat to populations of fish and marine mammals living in the area.
- Seabirds are assumed to be the most vulnerable ecosystem components with regard to an oil spill in this area. Even though oil avoids the vulnerable breeding and nesting areas along the coast, pelagic seabirds are present on the open ocean at all seasons and are likely to be affected given an oil spill.
- It seems highly unlikely that an accidental blowout in this area can escalate into one of the same magnitude as the Macondo-blowout in the Gulf of Mexico in 2010. Unfavourable weather conditions during a blowout seem to be the most uncertain factor that may contribute most to increase this probability.
- The model used for oil drift modelling is of high quality, and are continuously improved and configured by both SINTEF and DNV. However, as the exploratory drilling increases further east in the Barents

Sea, it should be assured that post-processing tools are able to illustrate oil drift in the entire Barents Sea and perhaps in the future also further into the Arctic Ocean.

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Appendix I - ERAs conducted in the Barents Sea

	Norvarg	Lunde Statoil	Lunde Statoil	Lunde ENI Norge	Goliat	Isbjørn (Obesum 1)	Obesum 2	Skrugard	Nucula	Nucula 2	Snøhvit oljesone	Askeladd beta	Tornerose	Ververis	Arenaria
Well	7225/3-1.	7119/12-4.	7119/12-4.	7120/12-5.	7122/10	7222/6-1S	7223/5-1.	7220/8-1.	7125/4-1.	7125/4-2.	7120/6-2 S	7120/8-4.	7122/6-2.	7226/2-1.	7224/6-1.
Permit	PL535	PL488	PL488	PL489	PL229	PL228		PL532	PL393	PL393	PL790A	PL064	PL110B	PL395	PL394
Operator	TEPN	Statoil	Statoil	ENI Norway	ENI Norway	Hydro	StatoilHydro	Statoil	Hydro	StatoilHydro	Statoil	Statoil	Statoil	StatoilHydro	StatoilHydro
Modelling tool	OS3D	OWM	OWM	OILTRAJ / BLOW	OILTRAJ / BLOW	OILTRAJ	GAP analysis			GAP analysis	OILTRAJ / BLOW	GAP analysis	OILTRAJ / BLOW	OILTRAJ / BLOW	OILTRAJ / BLOW
Period	mid 2011	late 2010	late 2010	late 2009	2010	jan 2008	nov 2008	okt 2010	des 2006	nov 2008	2006	okt 2007	aug 2006	mai 2008	juli 2008
Depth	370 m	192 m	192 m	181 m	325 - 390 m	370 m	332 m	373 m	290 m	303 m	326 m	275 m	404 m	331 m	267 m
Distance from coast	195 km	80 km	80 km	78 km	51 km	175 km	164 km	200 km	44 km	46 km	111 km	105 km	70 km	193 km	162 km
VEC´s	Note	Note	Note	-											
Fluid type	Realgrunnen oil	Tordis oil	Tordis oil	Kobbe oil	Realgrunnen oil Kobbe oil	Snøhvit blend Goliat oil Oseberg sør oil	Njord oil	Goliat blend 2	Realgrunnen oil Kobbe oil Njord oil	Realgrunnen oil Kobbe oil Njord oil	Snøhvit blend	Snøhvit blend	Norne	Goliat	Realgrunnen oil
Blowout rates (Sm3/day)															
Weighted rate topside	3217	5415	5415	4803		1430	682	5800	1710	1270	1000	1000	3500	1896	8098
Weighted rate subsea	2473	4867	4867	5943	3595	2350	366	4120	4310	650	1000	1000	3500	1896	3903
Duration of blowout															
Topside	Note	Note	Note	Note	Note	Note	Note	Note		Note	Note	Note	Note	Note	Note
Subsea	Note	Note	Note	Note	Note	Note	Note	Note		Note	Note	Note	Note	Note	Note
GOR	65 Sm3/Sm3	140 Sm3/Sm3	140 Sm3/Sm3	214 Sm3/Sm3	63 - 219 Sm3/Sm3	40 - 133 Sm3/Sm3		41			5050 Sm3/Sm3	5050 Sm3/Sm3	300 Sm3/Sm3	60.7 Sm3/Sm3	219 Sm3/Sm3
Time used for drilling relief well	35 days	56 days	56 days	50 days	45 days	40 days	47 days	50 days	40 days	40 days	40 days	40 days	47 days	42 days	45 days
Status today						Development is not very likely	New discoveries, not evaluated	Olje- og gassfunn (OD 01.04.11)	Development not very likely				Development likely but not clarified	New discoveries, not evaluated	Development is not very likely