


A school of brown cod fish swimming in clear blue water. The fish are the central focus, with several individuals in sharp focus and others blurred in the background. The water is a vibrant, clear blue, and the fish have a mottled brown and white pattern on their bodies. The overall scene is a natural, underwater environment.

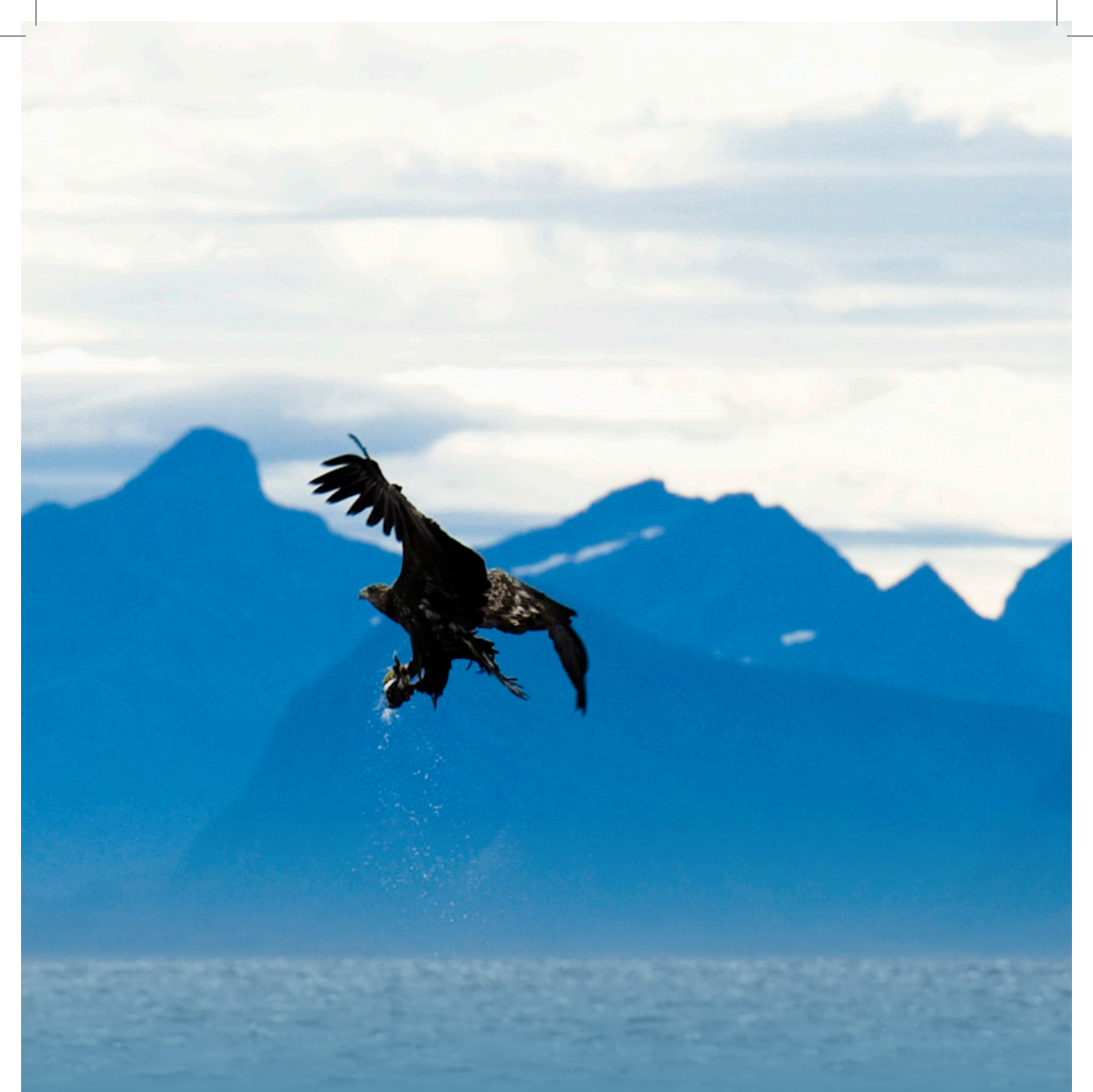
SYMBIOSES

Report



The simulation system “SYMBIOSES” was developed through a large R&D initiative with the aim to assess the effects of hypothetical oil spills on the Northeast Arctic cod stock. The system combines several individual models, including an oil fate and transport model, an oceanographic model, a model of the development of cod early life stages (eggs and

larvae), and a multi-species population model. The system addresses the effects of both acute and sub-lethal exposures of oil by cod early life stages. A worst-case oil spill scenario, with 4500m³/day for 90 days, resulted in a 43% reduction in the survival of cod early life stages in the year of the oil spill. Most discharge scenarios resulted in reductions in the

A bald eagle is captured in mid-flight, its wings spread wide, as it descends towards the water. The eagle is dark against the bright blue sky. Below it, a splash of water is visible, suggesting it has just caught a fish. The background features a range of blue mountains under a sky filled with soft, white clouds. The overall scene is serene and natural.

survival of eggs and larvae between 0 and 10%, with a corresponding reduction in the biomass of the adult cod population of less than 3%. In all simulations, including the worst-case scenario, the recruitment of juveniles to the adult population remained sufficient to maintain the reproductive capacity of the cod population. The Northeast Arctic cod stock is in good condition, making

it less vulnerable to recruitment losses. SYMBIOSES considers population losses that result from a decline in recruitment only for the year of the oil spill. Potential effects on other fish species or ecosystem components are not currently addressed. Further development of the system is planned to include other species and their interactions.

Introduction

This report presents the advanced model system SYMBIOSES - System for Biology-based Assessment. SYMBIOSES was developed to simulate the effects of hypothetical oil spills on the Northeast Arctic cod stock. This report includes a description of this simulation system and a summary of the results of a number of simulated oil spill scenarios for the marine ecosystem off Lofoten-Vesterålen, in the northern Norwegian Sea.

The natural beauty of the Lofoten Islands attracts tens of thousands of tourists each year to experience the region's rich aesthetic and cultural qualities. The marine waters off Lofoten-Vesterålen contain resources linked to Norway's three main economic drivers: tourism, fisheries/aquaculture and oil/gas. These waters are the key spawning area for the Northeast Arctic cod stock, herein referred to as 'cod'. In 2016, the commercial fishing industry harvested 900,000 tonnes of cod. There are also large oil and gas reserves located under the seabed that may become a future source of energy for the world. The Norwegian Oil and Energy Department estimates that there may be as much as 1.27 billion barrels of oil in the regions off Lofoten-Vesterålen, designated as Nordland 6 and 7 and Troms 2.

Norway has a comprehensive policy for the sound management of these marine resources based on principles established by the Norwegian Environment Agency (1):

"The ecosystem approach to marine management is an integrated management of human activities based on ecosystem dynamics. The goal is to achieve sustainable use of resources and benefits from ecosystems while maintaining ecosystem structure, functioning and productivity."

Norway became a world leader in marine environmental management with the implementation of an ecosystem-based management policy in 2005 (2,3). The European Union adopted a similar management policy approach in 2008 (4).

Managing the sustainable coexistence of petroleum and fisheries activities in the northern

Norwegian Sea requires sufficient knowledge of the potential effects of accidental discharges of oil into the environment. Two central questions to improve this knowledge basis are:

- 1) what would be the loss of cod larvae from the nursery grounds in the Norwegian Sea?
- 2) what would be the resulting impact on the harvestable cod stocks in the Barents Sea?

While the current SYMBIOSES simulation system addresses these questions for cod, the effect of an oil spill on other fish species will likely differ from cod due to, for example, differences in life history characteristics such as lifespan and spawning cycle. Other fish species may be more sensitive or more tolerant to oil than cod. Pollution effects on the local ecosystem and the potential effects of other industries, such as tourism and aquaculture, are not included in the current version of SYMBIOSES. Further development of this simulation system will include addressing the effects of oil spills on more species and species' interactions.

To determine the impact of oil spills on the cod population, integrative understanding of several key processes is required:

- Fate and transport of oil
- Distribution, movement and interactions between cod larvae and its prey (e.g. copepods)
- The relationship between biological effects and the toxicity of crude oil
- Effects on cod larvae exposed to oil components
- Natural mortality processes and population regulation mechanisms

It is not feasible to carry out real experiments of major oil spills to obtain the required integrative understanding of the above processes. The only practical way to assess the impacts of a major oil spill on fish is to conduct numerical simulations with advanced computer models, developed using the best available knowledge. Models are simplified representations of the real world, but they provide the required quantitative capacity

to integrate the relevant processes and to examine them over the correct space- and time-based scales. Models allow assessments of many possible scenarios, outcomes and consequences of oil spills on the environment. This was the conclusion of a review of 15 years of scientific research on the environment of Prince William Sound following the Exxon Valdez oil spill, and published in the top international research journal - Science (5). The authors concluded that there is a great need for risk assessment models to support pre-impact environmental decision-making as well as to obtain post-accident estimates of natural resource impacts. They also called for the development of advanced models that can evaluate chronic, indirect, and delayed effects of stressors, such as oil compounds taken up by marine biota. More recently, the European Food Agency, an advisory body to the European Union, has recommended integrating biology-based effect modeling into risk assessment methods.

The researchers who developed SYMBIOSES aimed to elucidate the two questions mentioned above. By combining, several advanced and well-established models into the SYMBIOSES simulation system, they are able to simulate in more realistic detail, the distribution, uptake and effects of oil on cod in the northern Norwegian Sea, from eggs until cod begin active swimming, and including realistic prey availability. They are also able to predict the development of the adult fish stock after an oil spill using calculations similar to those used to manage cod stocks. The SYMBIOSES model system also may be used to identify priorities for further research related to the effects of oil spills on cod stocks.

Cod

Adult cod originating from the Barents Sea spawn from early March to late April in several spawning grounds along the Norwegian coast. Eggs, larvae and juveniles drift with ocean currents to the north and east and into the Barents Sea. During August-September the juveniles remain in the top 100 meters of the southern Barents Sea, descending to deeper depths during autumn. Young cod grow up in the Barents Sea, becoming large enough to be fished at 3 years of age. At this age, they begin to be counted as part of the adult population. During spawning, cod produce large numbers of eggs. Due to changes in environmental conditions such as water temperature, ocean currents, light, turbulence, food availability and predation (6), only a small percentage of juveniles will survive. Approximately six out of one million eggs survive to enter the adult population at age 3 (7).

How was SYMBIOSES developed?

SYMBIOSES was designed and developed by a consortium of researchers from diverse institutions in Norway and abroad. Support was provided by a research grant awarded in 2011 by the Norwegian Research Council PETROMAKS program with additional support from BP Exploration Operating Company Limited, ConocoPhillips Skandinavia, ExxonMobil Upstream Research Company, Eni Norway, Shell Norway, Equinor, and Total E & P Norway. At the completion of the work in 2014, the system was fully developed, residing on the Norwegian high performance computer node at UiT – The Arctic University of Norway. SYMBIOSES was designed to be flexible, with possibilities to upgrade the system as new knowledge becomes available. A testing team was established consisting of specialists from Akvaplan-niva, the Norwegian Institute of Marine Research, SINTEF, and UiT – The Arctic University of Norway. The team received support through the Norwegian Research Council Demo 2000 program (2014-2016) to carry out the case study presented in this report. These research results are published in peer-reviewed scientific journals and presented at international research forums.

What are the components of the SYMBIOSES model system?

The SYMBIOSES model system integrates fish management modelling with oil risks and impacts in accordance with contemporary knowledge. The system was developed by applying an innovative strategy of linking pre-existing, well-tested, models together into an integrated simulation framework. The framework currently includes four independent models. Each model has been operational for many years, with individual upgrades and validation exercises performed over time.

The models calculate:

- Oil fate and transport (“oil”)
- Oceanography and ecology in lower trophic levels, i.e. phytoplankton and copepods (“ocean”)
- Movement and development of fish eggs and larvae from spawning areas along the coast (“early life stages”)
- Development of the spawning stock in the central Barents Sea (“cod”)

Oil Model

A 3-dimensional oil drift model (© SINTEF) is used to predict the transport and fate of oil in the marine environment. The behavior and fate of oil during a spill is governed by the properties of the oil, weathering processes, and ocean conditions. A chemical group approach tracks oil in its different phases (surface, entrained droplets, and dissolved) using 25 chemical groups. Each chemical group includes those hydrocarbons that behave similarly in the environment. The model has been applied in several major historical oil spill events (8), with good predictions of the transport and behavior of oil in the environment.

Ocean model

The ocean model, also developed by SINTEF, simulates ocean currents, temperature and salinity. Atmospheric conditions, freshwater discharges from rivers and land are the key driving forces in this model. The model simulates circulation in the Norwegian Sea and the Norwegian continental shelf. It has a component for the lower levels of the food chain in the marine ecosystem, to predict nutrient and phytoplankton concentrations (9). It simulates zooplankton population structure, development, spawning and distribution in the environment in response to the presence of food and water temperature. The model also simulates effects of the different chemical groups of oil on zooplankton (10).

Early life stages model

This model, developed by the Norwegian Institute of Marine Research, simulates the movements, growth, and mortality of cod from eggs to larvae stages, as well as physiological and behavioral responses to changes in environmental conditions (11). It tracks the development and distribution of drifting larvae until they become swimmers (~7 months). The model has been evaluated against observations from the Norwegian and Barents Sea.

Cod model

To simulate monthly changes in cod stock structure, SYMBIOSES adopted a “multi-species” model based on stock assessment methods used by the “International Council for the Exploration of the Sea” (ICES) (12). The model is maintained by the Institute of Marine Research. The version used in this project is based on assessments of cod stocks taken over more than 20 years. This database is also used to determine annual fishing quotas. The main variables are the number and mean weight of individuals (biomass) in different fish age/length groups. A number of biological processes are included such as growth, maturation, and mortality. The model uses the results from previous simulations of early life stages. The early life stages model tracks the development and distribution of drifting larvae until the start of the swimming stage while the cod model simulates fish starting from the end of their first year of life (January 1). A density-dependent mortality function is applied to adjust the density of the population from the early life stages model to the start of the swimming stage. The density of a population is defined as the number of organisms located in a defined area. An important factor regulating population density is cannibalism.

Model limitations

As of today, the simulations are limited to assess effects of oil exposure on cod stocks based on a single year’s decrease in recruitment. It does not include other impact factors, such as other contaminant sources and impacts from other industries. In all simulations, oil is assumed to not be present after one year and all surviving cod are healthy. Effects of oil spills on other fish species and ecosystem components around Lofoten-Vesterålen are also not included.

Models represent contemporary knowledge translated into simplified mathematical expressions. Results from models should be interpreted cautiously. Today’s knowledge of the life-history of early life stages of fish, their prey and predators, as well as knowledge of toxico-kinetic and toxico-dynamic properties of oil in various organisms is limited. These limitations should be considered when considering SYMBIOSES results in an ecosystem-based management context.

About cannibalism

- *Cannibalism is common in nature and occurs in hundreds of thousands of species.*
- *The majority of all fish species in Norwegian waters eat their younger brothers and sisters.*
- *Fish eggs, larvae and juveniles are abundant, but small, and therefore easy to eat. They have high nutritional value.*
- *For cod, cannibalism increases with the amount of juveniles available and when access to other prey species is reduced.*
- *Decreasing the amount of adult cod through fishing reduces cannibalism on younger fish.*

Ecotoxicological effects

The potential effects on organisms of bioavailable oil compounds are dependent on a variety of chemical, biological and physical factors. The effects are species dependent and can vary among different life stages of the same species. Early life stages are considered more sensitive compared to adult individuals. Among oil-related compounds, polycyclic aromatic hydrocarbon compounds (PAHs) are of greatest concern. The effects of PAHs can be chronic, such as delayed development, or acute (lethal). Biology-based models of acute and chronic effects are based on the concept that oil-related compounds induce effects to organisms when the concentration of an individual oil compound exceeds a 'threshold' value. The strength of the effect is quantified by the mortality rate. How quickly chemicals build up in an organism, and when the effect occurs after the threshold value is exceeded, is quantified using an elimination rate. The relationship between these parameters, the exposure time and concentration determines the effect. Safety factors are often applied to threshold levels as an additional precaution when there is limited data available to establish threshold levels with high confidence. The use of safety factors increases the likelihood of accounting for the most sensitive species and the most sensitive life stages.

How does SYMBIOSES simulate the toxic effects of oil on cod?

After an oil discharge event, bacterial degradation and evaporation are important mechanisms leading to the natural removal of hydrocarbons from the marine environment. Water naturally contains different types of bacteria, and oil is food for some strains of bacteria. After a discharge, the oil's physical and chemical properties change over time. This process is called weathering and relies on a number of factors including temperature, wind, ocean currents, sunlight, and weather conditions. Oil properties and weathering are important factors when applying oil spill mitigation techniques.

As previously mentioned, the chemical compounds of greatest concern are polycyclic aromatic hydrocarbon compounds (PAHs). Although PAH compounds are found naturally, human activities have also led to increased PAH levels in the environment. Degradation of PAHs occurs by bacte-

rial degradation photo-oxidation (via light), and chemical oxidation (13). These processes affect individual PAH compounds differently, because PAHs have different structural characteristics and physical, chemical and biological properties.

A number of effects of PAHs on fish have been demonstrated through controlled laboratory experiments. These include both acute effects, such as reduced survival, and chronic effects (such as cancer, genetic alterations, effects on development and effects on the immune system). The relationship between results from laboratory studies and effects in the field is complex. The effect on cod eggs and larvae exposed to oil depends on the exposure of different oil concentrations in the environment over time, and the properties of the oil. SYMBIOSES calculates effects on individual cod eggs and larvae as a function of chemical concentration in the water and water temperature.

The effect of oil exposure to oil by cod early life stages is simulated in SYMBIOSES using the DEBtox model approach (14), which is based on the "Dynamic Energy Budget theory" (15). DEBtox uses three parameters to assess toxicity:

- Threshold level is the lowest concentration of a compound group at which an effect will occur

- Mortality rate describes the strength of the effect
- Elimination rate characterizes the time to exceed the threshold level

Effects on cod eggs and larvae are the outcome of time-varying exposures to concentrations of oil in the environment and the properties of oil. SYMBIOSES quantifies the toxic effects of oil to biota through the simulation of time-varying exposures using threshold levels, rates, and intensities. This allows us to more realistically predict when and where the exposure to oil of drifting fish eggs and larvae causes effects. The concentration of a chemical that leads to an effect is known as a threshold level. The mortality and elimination rates are also important. At lower elimination rates, it takes longer to reach the threshold level, and the lower the mortality rate, the less toxic is the compound. The interaction between these three parameters results in different responses and sensitivities, depending on exposure concentration and exposure time (16).

The selection of values for threshold levels is an important consideration when examining the impacts caused by toxic exposures to oil. Traditional environmental risk assessment procedures quantify the immediate toxic responses of organisms to petroleum compounds using threshold levels derived from standardized laboratory tests, such as a 4-day survival test in the case of juvenile fish. However, a number of laboratory experiments have shown that the delayed on-set of defects can lead to reduced swimming performance, prey capture, and prey avoidance, potentially reducing survival and the number of juveniles recruiting into the adult population.

In SYMBIOSES, we selected threshold levels to address both immediate and delayed effects caused by exposures to the bio-available compounds in oil. To assure a comprehensive coverage of uncertainty, we evaluate effects using four different sets of thresholds, developed through expert consultations. The first set of threshold values (Level 1) was derived from available experimental data on different life stages of fish (eggs, larvae, juveniles, adults) with a safety factor of 50 for each chemical group (17). As sensitivity can vary widely from one species to another, safety factors lower threshold levels to provide additional precaution for the PAH chemical groups. A safety factor was applied to Level 1 to ensure coverage of the most sensitive species and life stages. Level 2 is the same as Level 1 but with a safety factor of 500. A higher safety factor was applied in Level 2 com-

pared to Level 1 to account for toxic mechanisms of PAHs currently not covered by existing models.

All three ecotoxicological parameters available in the DEBtox model (threshold level, mortality rate, elimination rate) were used to calculate effects in Level 1 and Level 2. Threshold Level 3 does not consider time-varying processes (mortality rate and elimination rate) for the PAH chemical groups; mortality is instantaneous when an organism is exposed to PAH concentrations of 1.0 part per billion or higher (Level 3). Level 4 is based on the same principle as Level 3; instantaneous mortality occurs when an organism is exposed to PAH concentrations of 0.1 parts per billion or higher. In Level 3 and Level 4, instantaneous mortality is applied to ensure that the potential on-set of delayed effects are accounted for in our simulations. Level 3 and Level 4 are designed as an acknowledgment of the limitations of current knowledge and the potential for further reducing threshold levels in the future.

How are SYMBIOSES results reported?

In this report, we discuss the cumulative survival from eggs up to the age that larvae begin swimming and the biomass of the adult standing stock for each of the four ecotoxicological parameter sets (Levels 1-4). After following spawned eggs to the swimming stage, we quantify the difference in the population size both with and without an oil spill. After first correct for density-dependent mortality, we simulate the development of the adult population for ~10 years post-spill. We measure the impact as a reduction in the biomass of the adult population resulting from an oil spill compared to an unimpacted adult population. This impact is quantified ~7 years after the oil spill, when the affected juveniles make up the largest fraction of the adult biomass.

Addressing question 1 - what would be the loss of cod larvae- we discuss the percentage differences in the cumulative survival of eggs and larvae between comparable simulations with and without oil.

Addressing question 2 -what would be the impact on cod stocks- we discuss the percentage differences in the biomass of the adult cod stock with and without the effects of a major oil spill.

Case Study of cod

We simulated discharges of two different types of oil from a position on the continental shelf at Nordland VI (67.700N 10.841E). All simulations began on March 1 to coincide with the first release of cod eggs from nine spawning areas along the Norwegian coastline. Simulations were performed for the years 1995, 2001, and 2002. Using a selection of years in which the size of the juvenile stock and the age structure of the adult stock varied, allows us to examine how stock variations are linked to the outcome of an oil spill. In 1995 the biomass of adult cod was estimated to be 530,000 tonnes, in 2001 it was 360,000 tonnes and in 2002, 505,000 tonnes. We selected release rates of 1500 and 4500 m³/day lasting 14, 45, and 90 days. The total volume of oil discharged into the sea was 18-349 × 10³ metric tonnes. Our longest release rate (90-day) is comparable to the duration of the Deepwater Horizon (DWH) spill. However, oil release rates are controlled by reservoir characteristics, which on the Norwegian shelf are approximately half the rate of oil discharge in the case of the DWH spill. Therefore, our maximum oil volume is about half the volume discharged during the DWH spill. No oil spill remediation is included in these simulations.

A total of 38 unique scenarios of discharge rate, depth of discharge, discharge duration and type of oil (scenarios) were simulated for all four ecotoxicological parameter sets (Levels 1-4), a total of 152 oil spill simulations. We simulated 20 surface (top-side) and 18 sub-sea discharge scenarios. We also simulated each of the 38 scenarios without oil discharges in order to compare the development of the cod cohort with and without the impact of oil.

What is the loss of early life stages of cod from the nursery grounds?

Levels 1 and 2 include the time-varying effects of oil compounds accumulating in biota. For all of these simulations, there is no difference in cod survival with and without an oil spill. Survival was reduced for simulations carried out with Levels 3 and 4 where we apply instantaneous mortality to eggs and larvae exposed to low concentrations of PAHs. Most scenarios resulted in 0 - 10% reductions in survival relative to a no oil scenario. Not surprisingly, we obtain the highest reduction in survival for the highest discharge rate (4500 m³/day) combined with the longest spill duration (90 day). The maximum reductions in survival are 14% (Level 3) and 43% (Level 4). For all oil spill scenarios, reduced survival resulted in no impairment in the recruitment of juveniles into the adult stock.

success depending on the influence of environmental conditions on the survival of young fish. A depleted adult population will produce fewer eggs, which may lead to reduced recruitment depending on environmental conditions. The cod stock is well-managed, and even the most conservative assumptions for mortality due to oil exposure, did not reduce the population of adult fish to a critical level. If needed, a temporary reduction in fishing can be applied to compensate for population reductions. For cod, the 6-7 years between juvenile recruitment and maturation provides a time window in which to consider such mitigation measures.

What is the effect on cod stock in Barents Sea?

Following the cod population as it developed in response to reduced survival of young cod resulting from oil spills, we found no discernible reduction in adult biomass when applying Levels 1 and 2. A minor reduction in adult biomass occurred for Level 3 (<3%) whereas our most conservative set, Level 4, resulted in a reduction in the adult biomass of <12%. Based on all simulations, the stock will remain at full reproductive potential with a sufficient number of juveniles surviving to replenish the adult stock.

Significance of the results of this case study

Sustaining fish stocks requires ongoing recruitment of a sufficient number of juveniles to the adult population. Healthy fish stocks produce more eggs than can survive, with recruitment

The SYMBIOSES simulation results indicate less impact on cod than many thought. Why are these losses lower than previously assumed?

- **Oil entering the sea evaporates and degrades**

In the immediate aftermath of an oil spill, oil concentrates at the sea surface resulting in evaporation of the most volatile compounds. In subsequent days, oil disperses through wind, mixing, and currents, and is broken down via photo-oxidation and biodegradation processes (12). In our simulations, evaporation and biodegradation accounted for the loss of 43-61% of the oil discharged into the sea. Most of the remaining oil was widely dispersed, with only a minor fraction of oil (< 3%) reaching the shoreline.

Approximately 40-60% of the discharged oil was removed through evaporation and biodegradation processes

- **We simulate more realistically the interactions of oil with biota**

Using the SYMBIOSES simulation system we are able to track variations in the movements and distributions of individual cod and its prey in time and space together with changing concentrations of oil compounds in the environment. We also accounted for time-varying oil exposures in the assessment of biological effects. Our simulations indicate that cod encountering an oil spill in Nordland VI are exposed to generally low concentrations of oil in the open sea. In most scenarios, the resulting impact on survival is low, even with application of our most conservative ecotoxicological parameter set (Level 4) to account for delayed toxic effects.

In this particular area, major oil spills resulted in limited effects on cod eggs and larvae.

- **Oil spills impact a single generation of cod, while the adult population of cod consists of fish from many generations**

The biomass of the adult cod stock in the Barents Sea consists of fish ranging in age up to more than 13 years. Species that have several age classes contributing to the biomass of the population are weakly impacted by severe mortality events affecting a single generation of individuals (18). As a result, major losses to a single generation do not directly translate into equivalent changes in the abundance of that generation at older life stages.

In the present case study, the losses obtained for a single generation do not lead to an impact on the biomass or future reproduction of the Northeast Arctic cod population.

The diverse age distribution of the cod population serves to protect the stock from the impact of an oil spill on a single generation of recruits.

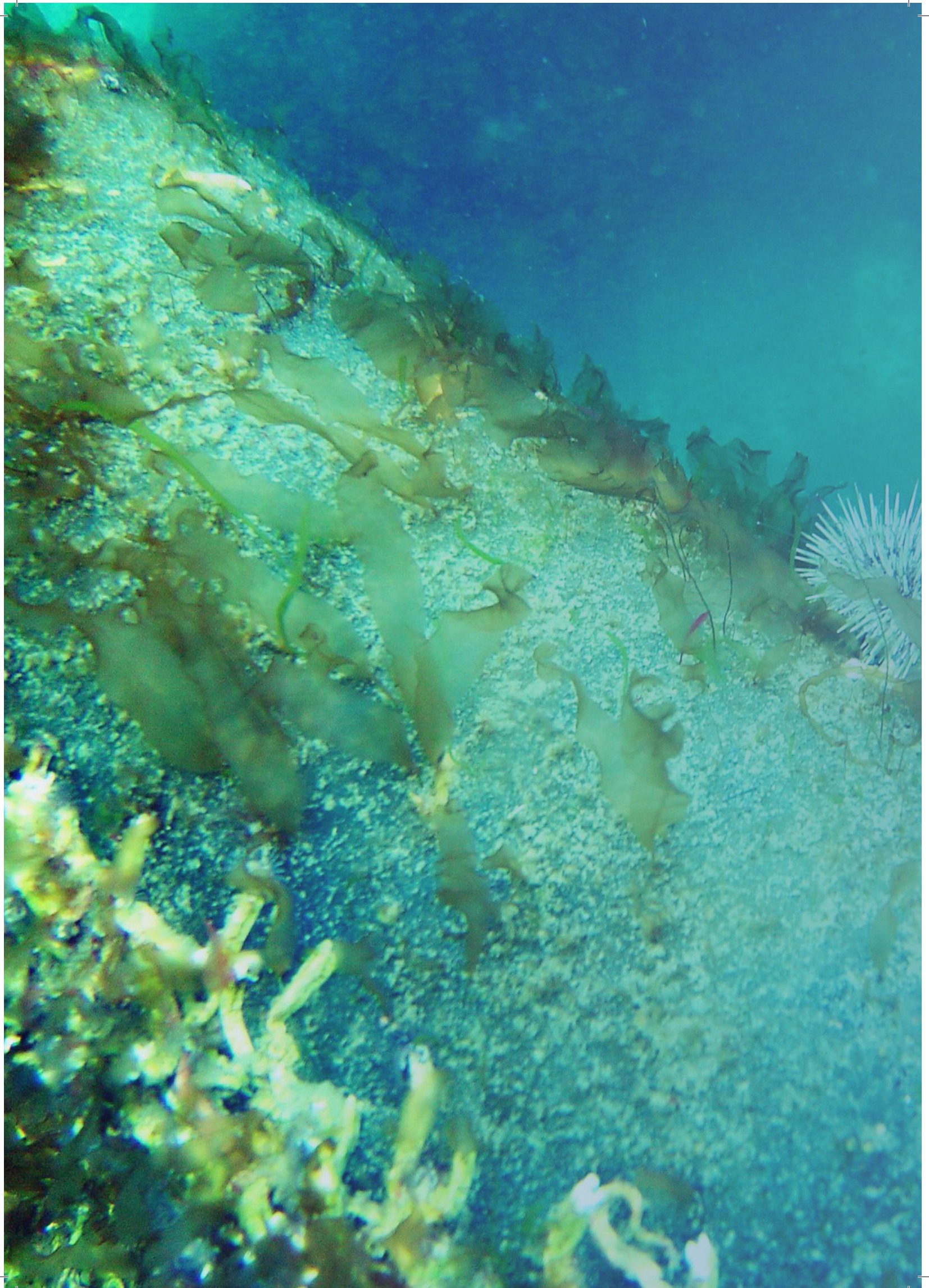
- **The population is healthy and therefore less vulnerable to losses in the recruitment stock**

Many factors influence the development of fish stocks. Rapid stock fluctuations are attributed to environmental variability and species interactions, whereas slow fluctuations are associated with external forcing factors, such as overfishing and climate variability. For a healthy stock, the typical pattern is a majority of poor to average years of recruitment, and only a few highly successful years. Low pressure from fisheries in recent years and high recruitment in 2004-2005 has resulted in high cod abundances and a diverse age distribution in the stock. These trends minimize the potential for declines in the cod stock. The stock size is presently well above the level required to maintain full reproductive capacity, and the population is currently at least as resilient, and probably more resilient, to reductions in a single year's recruitment as in the 1990s and early 2000s.

A healthy population is more resilient to recruitment losses.

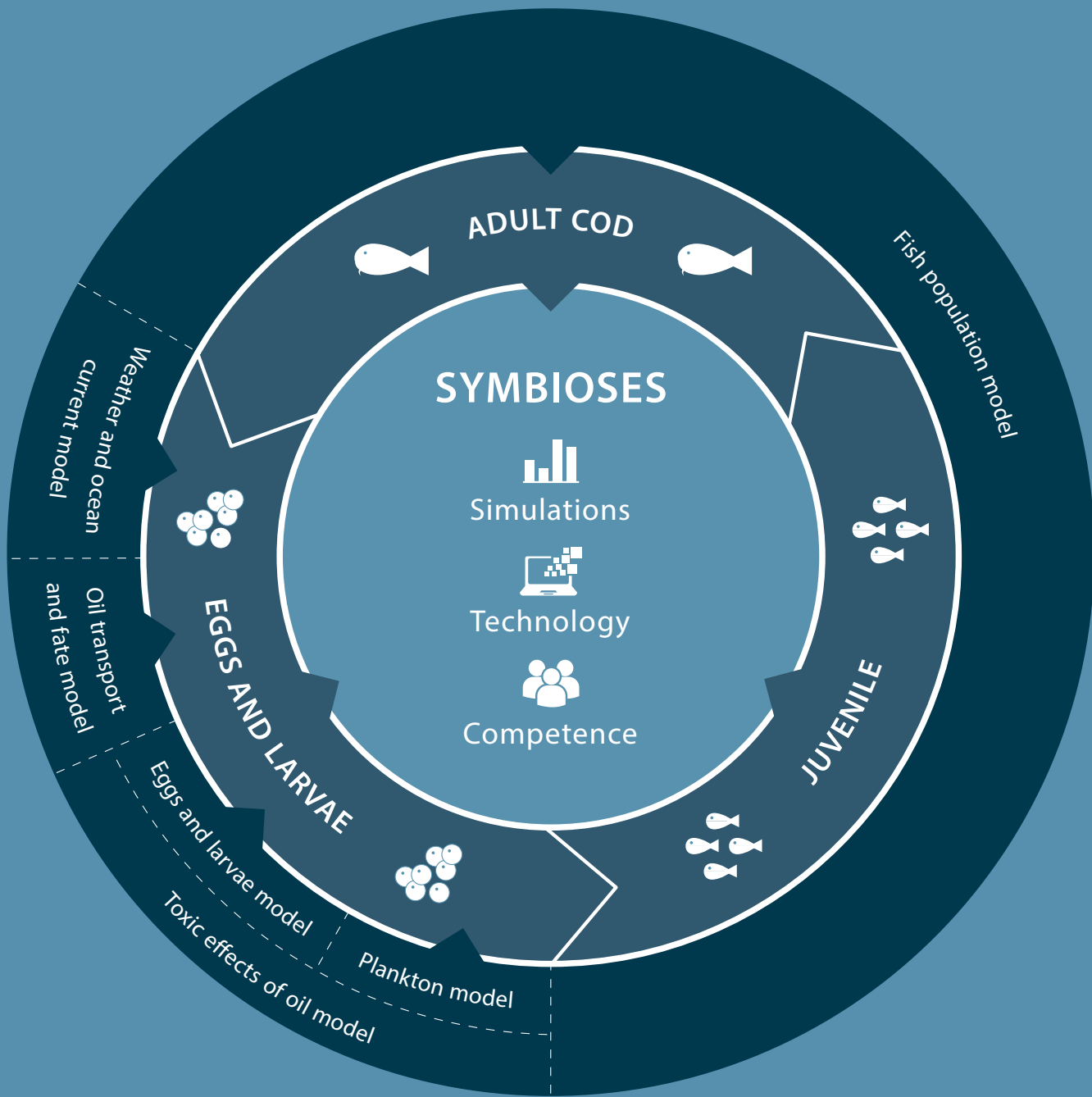
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Conclusion

- Most discharge scenarios (based on a single year's decline in recruitment) resulted in a decrease in survival for eggs, larvae and young fish of $\leq 10\%$ in a year class. A worst-case (maximum discharge rate, longest duration, no oil spill response, start of the spawning season) resulted in a 43% reduction in survival in the cohort.
- The results of the simulations indicate that recruitment of young fish to adult population remains sufficient to maintain the reproductive capacity of cod, even with the worst-case scenario.
- Most emission scenarios reduce the biomass of the adult population less than 3%. A worst-case scenario resulted in a 12% reduction in the adult generation.
- Mitigation measures in the form of reduced fish quotas can reduce the impact on the adult cod stocks.
- The population is less vulnerable to recruitment losses partly because the stock is healthy, and thus has a buffer against potential losses.
- Losses from a single year's decline in recruitment in cod stocks was modelled. Potential effects on other species or ecosystem compartments around Lofoten are not addressed.
- Other factors such as potential long-term effects, other types of contamination, and potential impacts of other industries are not included in SYMBIOSES.



SYMBIOSES –

An ecosystem-based modeling system for predicting potential impact on the Northeast Arctic cod fishery from petroleum accidents

As a substitute for real-life experimentation, combining proven scientific models allowed us to examine how an oil spill would impact on cod stock within relevant space and time-based scales;

- To simulate the effects on fish eggs and larvae an oil fate and transport model was combined with a model simulating plankton growth and the development of eggs and larvae in the environment.
- For juvenile and adult cod a well-established model for predicting the development of the fish population – also used to calculate fishing quotas – was utilized to simulate effects, with and without an oil spill scenario.

152 oil spill simulations, with a wide range of data, were performed on the nursing grounds of the Northeast Arctic cod, focusing on

- how oil is transported
- the biological effects of oil compounds
- the behavior and interaction of biological material in the environment.

The simulations focus on the toxic sensitivity of fish eggs and larvae to oil, addressing both immediate and long-term effects of an oil spill.

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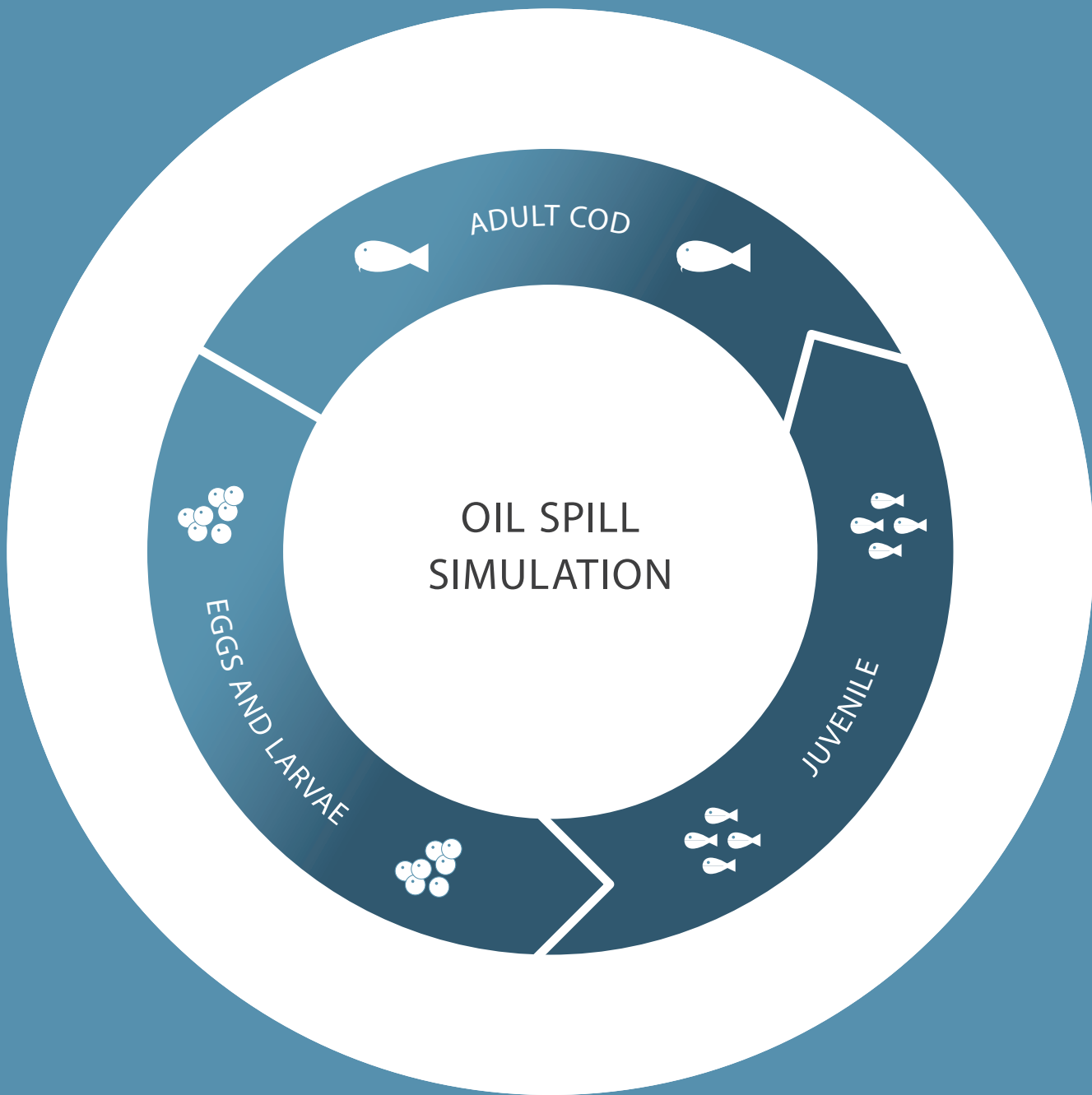


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For more information about SYMBIOSES and the impact simulation results c

Northeast Arctic cod stock is more robust against oil spill impacts than assumed

- Our simulations of major oil spills suggest that recruitment of juveniles into the adult stock is sufficient to maintain the reproductive health of Northeast Arctic cod
- Most oil spill scenarios reduce the biomass of the adult stock by less than 3%. A worst case scenario leads to a 12% reduction in the adult stock biomass
- The North Arctic cod stock remains at a sustainable level

For more information about SYMBIOSES and these simulation results, contact head of project, JoLynn, jc@akvaplan.niva.no



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