Biological Impact of Oil on the Sea Ice of the Arctic

a report by

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The Sea-ice Ecosystem of the Barents Sea

The Barents Sea is the largest among the pan-Arctic shelf seas, covering about 30% of the shelf surrounding the Arctic Ocean. Forty-nine per cent of the total pan-Arctic shelf's primary production takes place in the Barents Sea. This allows the Barents Sea to support a rich biological diversity, including: big fish stocks; some of the world's most numerous colonies of sea-birds, such as little auks, puffins and guillemots; rich sea-floor communities with kelp forests; and a unique variety of marine mammals such as walruses, seals, whales and polar bears. Sea ice can cover up to 90% of the surface of the Barents Sea in winter, but there is no locally produced year-round ice. Thus, much of the Barents Sea experiences ablation and growth of sea ice on a seasonal basis. The seasonal ice in the northern part of the Sea plays a key role in the function and structure of the ecosystem by providing a habitat for highly specialised sea-ice-living creatures, from sea-ice algae and small crustaceans up to fish. This habitat sustains many species of birds, seals, walruses, belugas and polar bears. In this article we will discuss the sympagic fauna – marine organisms that live in association with sea ice during their whole life-cycle. The most abundant and diverse group of sympagic fauna in Arctic seas are crustaceans, especially amphipods and copepods, which comprise up to a maximum of 15 species; in comparison, two fish species have been recorded. The polar cod feed on the sympagic fauna, as do the birds and mammals that forage into the ice-pack.

The seasonal ice in the northern Barents Sea has its origin in the Arctic Ocean; it may have been formed close to the Siberian or North-American shelves, then drifted for several years across the Arctic Ocean before ending up in the Barents Sea. However, it is also common for ice to form in the Arctic Ocean or the northern Barents Sea, offshore or between the Svalbard and Franz Josef archipelagos. The different origins and histories of individual ice floes results in variable size, thickness, texture, structure, snow cover and food availability, which means the distribution of the ice fauna is extremely variable and patchy. It is not uncommon for one ice floe to be inhabited by only a few individuals while the neighbouring floe harbours an abundance of life. Moreover, in the Barents Sea and other Siberian Shelf seas the marked inter-annual variability of the inflow of water from the Atlantic Ocean, the import of old ice from the Arctic Ocean, the freeze-and-thaw cycle and the irregular ice-drift pattern play major roles in determining the nature of the sea-ice community structure. Apart from the scarce food supply, the major environmental challenges in Arctic waters for these organisms are extreme physico-chemical variations caused by melting and thawing and wave action, rafting and ridging. Sympagic ice fauna species are well adapted to the sea-ice environment through their physiology, morphology and behaviour. Additionally, many Arctic species have a circumpolar distribution.

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Renewable and Non-renewable Economic Resources in the Barents Sea

The Barents Sea is also a place of great economic interest. The fisheries resources in the area are among the richest in the world. The commercial stocks are well regulated by Norway and Russia and are generally in good shape, generating a considerable level of economic activity in both countries; the stocks are also exploited by Iceland, the Faroe Islands and EU countries. Coal mining takes place on Svalbard, and major mineral sources have been discovered both in Greenland and on Novaya Zemlya; however, these have not yet been exploited. With increasing global energy demand and high oil prices, the Barents Sea has become a main focus of attention in the oil industry. The world's largest offshore gas reserve, Shtockman, has recently been discovered in the Russian sector of the Barents Sea. Discussions are ongoing as to how and when to develop the giant field. Beginning in 2007, liquefied natural gas (LNG) from the Snøhvit field will be produced in the Norwegian sector to supply the world market, while the Goliat oilfield – also in the Norwegian sector – will enter its production phase in the coming decade. In the Russian sector, the Prirazlomnje oilfield is expected to come onstream in 2010. Recently, the Norwegian giant StatoilHydro revealed a promising oilfield called Nucula, which is located several kilometres off the North Cape. Additionally, the increase in offshore oil and gas industrial activities, as well as in onshore development in north-west Russia, means there will be much more maritime traffic along the coasts of Russia and Norway.

Oil Transportation Through the Barents Sea

Before 2002, oil transportation from the Russian part of the Barents region along the Norwegian coast occured only in insignificant volumes. However, in 2002 there was a dramatic increase in oil shipment, with 4 million tons of oil transported along the northern regions. In 2003, the volume reached 8 million tons, and this trend continued in 2004, when approximately 12 million tons of export oil and oil products were delivered from the Russian part of the Barents region to the western market along the Norwegian coast. A new terminal at Varandey in Nenets Autonomus Area on the coast of the south-eastern Barents Sea is planned to open in 2009, which alone will have a capacity of 15–30 million tons of oil per year. According to analysis carried out by the Norwegian authorities, the annual export of Russian oil being shipped along the Norwegian coast may reach the volume of 50–150 million tons in the next decade. This volume of oil transportation depends on the construction of a new trunk pipeline to the Russian coast of the Barents Sea from the onshore oilfields in north-west Russia and western Siberia. This increase in oil transportation brings an increased risk of accidental discharges of crude oil, with subsequent drift and incorporation into sea ice. In recent years, there has also been a large increase in the number of tourists visiting the Barents Sea and Svalbard. The risk of accidents with big cruisers in rough and unpredictable coastal waters is growing every year.

Ongoing global warming has led to reduced amounts of ice, which makes sea transportation and offshore oil and gas activities easier and less risky, as well as expanding the geographical area for such activities. On the other hand, thawing of permafrost has led to major onshore infrastructure problems in mainland Russia. The extensive Russian pipeline system for the transportation of oil and gas has been shown to be vulnerable, and it is becoming even more vulnerable as the permafrost disappears. Accidents have occured, the biggest one being in 1994, when more than 100,000 tons of oil were released into the terrestrial environment in the northern part of the Komi Republic along the Pechora River, a major north-flowing river that carried oil and related waste to the Barents Sea. As anthropogenic activities gain momentum in the Barents Sea, numerous issues need to be tackled to ensure that this marine ecosystem is protected and passed on to future generations in good shape. The main challenge is to guarantee that the fishing industry together with increasing maritime traffic and new petroleum activities do not constitute a threat to the environment. Therefore, a set of environmental measures needs to be taken to protect the Barents Sea for the future as a basis for sustainable welfare and wealth.

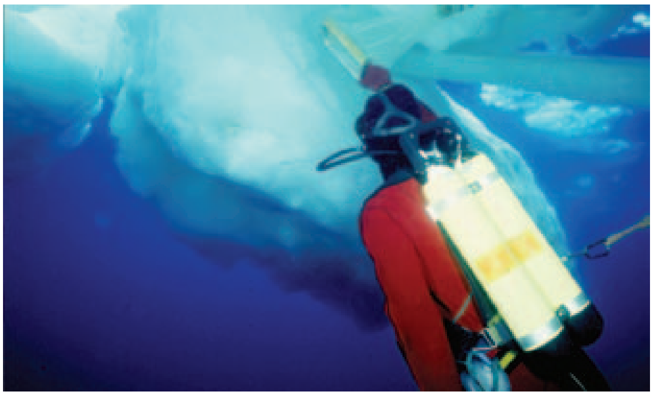
The 'Zero Discharge' Policy for the Oil Industry in the Norwegian Barents Sea

Among the goals set to guarantee the protection of the northern seas, the Norwegian authorities promulgated a 'zero discharge' policy in the Norwegian part of the Barents Sea, from the Islands of Lofoten northwards. With this regulation in place, environmental concerns are related more to accidental discharges such as well blow-outs, boat wreckage and pipeline leaks. Operating companies have worked systematically for many years to reduce discharges into the sea to the minimum possible, and to adhere to the 'zero harmful discharges' regulations for the Norwegian shelf. The stricter 'zero discharge' requirements in the Barents Sea mean that efforts must be intensified with regard to developing and implementing new techniques that eliminate discharges to the sea. The waste and produced water have to be re-injected or transported to the shore for treatment. In addition, the Russians have introduced a similar 'zero discharge' policy in their sector of the Barents Sea, and are developing a control regime for enforcing this policy.

Oil and Ice

Significant research – including field tests and observations, laboratory tests and numerical studies – has been carried out with the aim of understanding the physical, chemical and biological impact of oil discharged in waters where ice is present. Research has often been conducted using laboratory or test tanks. There have been several significant field experiments and much has been learned from accidental spills in ice-infested environments. Oil spilled in ice-infested waters undergoes complex behavioural and fate processes. The highly

Figure 1: Ice Sampling



Photograph by Bjorn Gulliksen.

dynamic system of sea ice – characterised by large variations in salinity, high ultraviolet illumination during summer and the big discrepancies in the structure of sea ice – explains the complexity of the behaviour and fate of oil in sea ice. More research, especially quantitative, is needed before it will be possible to predict oil behaviour and fate in ice-infested environments. In addition, much of the work is now 20 years old, and some measurement methods have improved to the extent that older results may not be valid.

Impact of Oil on Sea-ice Animals

To date, there are virtually no toxicity data available on sea-ice organisms. This is in contrast to the US Environmental Protection Agency (EPA) database on toxicity studies, which comprises 220,000 records for aquatic temperate species and includes records on 4,000 species and 7,000 chemicals. There is therefore a need for urgent action to fill up this large gap in our knowledge. The highly complex behaviour and fate of oil in sea ice pose numerous challenges when attempting to decipher the impact of oil on the living creatures that inhabit the sea-ice ecosystem. However, if we are to provide the industry and authorities with an estimate of the risks posed by an accidental oil spill on the sea-ice ecosystem, we need to understand how the sea-ice organisms respond to oil components. At Akvaplan-niva, we are currently working on several large research projects that aim to provide toxicity data on the effect of oil components on three key animals located at different levels of the food chain in the sea-ice ecosystem. First are the Arctic copepods *Calanus glacialis* and *Calanus hyperboreus*: these animals are herbivorous – they graze on unicellular algae (phytoplankton) – and represent the first link between the primary producers and the rest of the food chain. Second is the sea ice amphipod *Gammarus wilkitzkii*: highly abundant in pack ice, it is omnivorous but preferentially feeds on the copepods, and is well adapted to the high variation in salinity that characterises the ice ecosystem. Third is the polar cod *Boreogadus saida*: a member of the cod family, adults weigh 20–30g and are up to 15cm long. Thanks to its antifreeze physiological system, the polar cod can live in sub-zero seawater, where ice formation can be intense during winter.

We have addressed six main research objectives in these projects, as detailed below.

Research Objective 1

The first objective is to develop methods for sampling the animals living in the sea-ice habitat and to rear them in aquariums by developing 'aquaculture protocol'. This will ensure that a healthy and unstressed stock of animals is available in a sufficient quantity for toxicity testing. Sampling animals requires the use of ice-class research vessels to reach the ice edge and a variety of sampling gear – trawlers, plankton nets or divers using suction pumps (see *Figure 1*) – to collect animals living underneath the ice pack without harming them. Most of our research on fish is carried out at the Kings Bay Marine Laboratory at the research station of Ny Ålesund on Svalbard, while smaller animals are transported to Tromsø, Norway, where experimental research is performed using Akvaplan-niva's facilities.

Research Objective 2

The second objective is to measure the lethal dose of a chemical that kills 50% of tested animals. The lethal dose is known as LC50 and can be directly incorporated into risk assessment models such as 'Environmental Impact Factor–Acute', which was developed in Norway by operating companies.

Research Objective 3

The third objective is to develop exposure systems to simulate an oil spill in the laboratory to which animals can be exposed. By teaming up with scientists who worked on the long-term (17-year) impact of the Exxon Valdez oil spill in Alaska, we implemented a system that allows us to simulate an oil spill scenario in the laboratory.

Research Objective 4

The fourth objective is to measure the seasonal variability of well-known biological effect parameters (also called 'biomarkers'). To date, biomonitoring in Norwegian waters employs biological effect parameters. Although the responses of these biological effect parameters are tested in well-controlled laboratory experiments, numerous natural variables (temperature, salinity, food supply, sea-ice presence) alter their background levels. It is therefore very important that we get to know the seasonal variation in these biomarkers by sampling animals at different times of year. This is possible only by working closely with Arctic marine ecologists who have field expertise, which helps us to understand where the animals are at which times of year.

Research Objective 5

The fifth objective is to measure the responses of biological effect parameters selected for offshore biomonitoring programmes in the North Sea shelf in terms of the effect of oil components on Arctic animals, using the oil-spill simulation system in the laboratory.

Research Objective 6

The sixth objective is to investigate the interactions between oil components and physiological specificities of Arctic animals, such as the antifreeze processes in the polar cod.

Finally, since these species have a pan-Arctic distribution, each project has a pan-Arctic perspective involving researchers from Norway, Alaska, Canada and Russia. In this respect, Akvaplan-niva has initiated a Pan-Arctic Network of Experts on Environmental Issues associated with Petroleum Development in the Arctic (PANEP) in order to foster the development of cutting-edge research projects and enhance synergy between scientists with similar research interests. Only in this way will scientific expertise be produced and passed on to the authorities, regulatory bodies and industry to ensure protection of the sea-ice ecosystem. ■