2005

POLAR RESEARCH IN TROMSØ

POLARMILJØSENTERET

INSTITUTE OF MARINE RESEARCH
HAVFORSKNINGSINSTITUTTET

UNIVERSITETET I TROMSØ

New possibilities

This year saw two welcome additions to our possibilities to carry out research in polar areas – north and south. For the first time ever, Norway's Antarctic research station "Troll" has been manned year-round: seven people spent the entire Austral winter there. One of the most important improvements at the station is an airstrip on a patch of glacial blue ice a few kilometres away. The construction work required wholly new techniques and was quite a challenge for the Norwegian Polar Institute, which operates Troll. It is anticipated that the station will be a major asset during the International Polar Year 2007-2008.

At the other end of the globe, the new Arctic Marine Laboratory in Ny-Ålesund opened its doors to researchers in the fields of marine ecology, physiology, biochemistry, ecotoxicology and physical marine science. Scientists from the Polar Environmental Centre were closely involved in the planning of this facility, owned and operated by Kings Bay A/S. At the opening, Prime Minister Kjell Magne Bondevik spoke of "a new era for the international research community in Ny-Ålesund", then looked beyond the scientific potential. "Research is necessary in order to increase our knowledge," he said. "But research also has another, equally important dimension: it promotes communication and cooperation between people and nations, and thus contributes to political stability and peace."

A sea of opportunities

International cooperation was also a strong theme when Foreign Minister Jonas Gahr Støre visited the University of Tromsø in November. Speaking before an enthusiastic audience, he presented a new initiative for research and development in the High North: "Barents 2020". Two areas are seen as particularly important: developing petroleum technology and mastering the challenges of environmental and resource management. Gahr Støre called for innovation, "thinking along new lines", but added that future efforts would "build on the important work being done at institutions like the University and the Norwegian Polar Institute here in Tromsø, the Institute of Marine Research and the Research Council of Norway, and on the petroleum and technological expertise found in leading Norwegian companies." Gahr Støre challenged Tromsø and Northern Norway to take the lead in this process.

New partner joins Polar Research in Tromsø

As of this issue, the Tromsø branch of the Institute of Marine Research joins the Roald Amundsen Centre for Arctic Research, the Norwegian Polar Institute and the Polar Environmental Centre in publishing Polar Research in Tromsø. Welcome!

Tromsø, December 2005
The Editors

Polar Research in Tromsø

Polar Research in Tromsø is published at the end of each year by the Roald Amundsen Centre for Arctic Research at the University of Tromsø, the Norwegian Polar Institute, the Tromsø branch of the Institute of Marine Research and the Polar Environmental Centre, Tromsø, Norway. Its aim is to provide glimpses of some of the education and research in polar (chiefly Arctic) studies carried out at these institutions and at research institutes and companies in the Tromsø area with which they have close ties.

It is sent on request and free of charge to all persons who are interested in polar studies.

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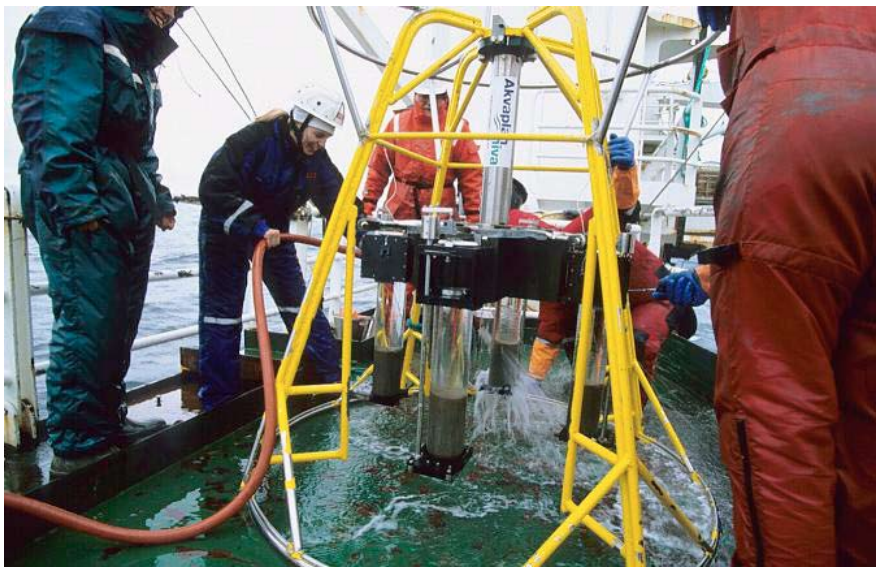
Assessing the environmental effects of offshore oil activities on benthic ecosystems in the Arctic



The multicorer device used to take sediment samples

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As oil and gas industries are moving North into the Norwegian sector of the Barents Sea it is important to address knowledge gaps on the potential effects of petroleum activities on multiple scales of biological organisation from cellular, to individual, to whole communities, populations and entire ecosystems. Benthic organisms play a key role in arctic food webs as these organisms serve as important prey items for higher trophic level organisms such as several commercially important fish species, as well as shrimp and walrus. Under the "no discharge" regulatory framework for the Barents region, environmental impacts will be the result of accidental releases involving production, processing or transport activities carried out by the petroleum industry. Many benthic organisms are sedentary and thus are unable to escape an environmental event such as an oil spill.

It is in this context that we are looking at the sensitivity of benthic organisms and communities to acute spills of petroleum related chemicals and routine discharges of water-based drill cuttings. First results from a series of controlled laboratory experiments carried out on whole sediment communities of soft-sediment benthic organisms, show effects in two key community-level response indicators: changes in respiration (oxygen consumption) and bioturbation (mixing of sediment by biota). We observe higher oxygen consumption rates in both drill cuttings and chemical treatments compared to our controls. Bioturbation activities also show differences among the various treatments: in the case of drill cuttings, organisms burrow deeper in the sediment, signifying a possible escape effect.

Measuring oxygen consumption in sediment communities

Experiments on individual species of Arctic bivalves and amphipods were carried out at the Ny-Ålesund Laboratory where organisms were exposed to water-based drill cuttings and petroleum-associated contaminants. Observed responses to the various treatments included decreased burrowing activity into the sediment, changes in the bivalve's position in the sediment, and a higher mortality compared to experimental controls (no chemical or drill cuttings additions). We will soon expand on these effects indicators by examining chemical body burdens in animals, conducting malformation experiments on embryonic development and measuring cellular energy allocation (CEA), the latter being a useful marker of biological exposure (biomarker).

We currently do not know whether there are differences in the sensitivity of arctic and more temperate latitude benthic species and communities to petroleum-related discharges. To begin to address this important question, both our community level and individual level experiments were repeated in Summer 2005 at the Norwegian Institute of Water Research's field station, Solberstrand in Oslofjord. Preliminary results show several differences in treatment responses between temperate and arctic dwelling organisms. However, organisms in both areas are vulnerable to oxygen limitations caused by drill cuttings deposited on the sea bottom.

Financed through the Norwegian Research Council, PROOF programme, the project is providing valuable new information on possible risks for arctic biota from petroleum development activities. These findings will improve the use of benthic monitoring data as an assessment tool and will support the development of appropriate risk management systems applicable in diverse environmental regions of Norway.

Perfluoroalkylated substances (PFAS) in an Arctic food web

Figure 1. Sampling of glaucous gulls at the ice edge southeast of Svalbard.

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For many years environmental chemists have focused on persistent organic pollutants (POPs) as major environmental contaminants. Traditionally, all compounds that have been regarded as POPs have been hydrophobic. A hydrophobic compound is more soluble in lipid than in water, conferring to the compound the propensity to bioaccumulate. The concentration of such compounds, e.g., polychlorinated biphenyls (PCBs) and chlorinated insecticides such as DDT, increases in the food web so that higher trophic levels have higher concentrations than the basal trophic levels. Recently, however, it has been shown that a compound need not be hydrophobic to bioaccumulate.

Perfluoroalkylated substances (PFAS) are a set of compounds that all have an alkyl chain on which all hydrogen atoms have been replaced with fluorine. Although this fluorinated alkyl chain is hydrophobic, the molecule also contains a hydrophilic functional group, e.g., a carboxylate or sulphonate. This combination of hydrophobic and hydrophilic properties in the same molecule is typical of surface active detergents. The first PFAS to be noticed as an environmental contaminant was perfluorooctane sulfonate (PFOS), which, among other things, is used as surfactant in fire fighting foams. Until the discovery of PFOS in biota it was thought that compounds with a highly hydrophilic group, such as sulphonate, would not bioaccumulate. This conjecture was obviously wrong, and the behaviour of different PFAS in different food webs needs to be investigated further.

The present study was performed on species from an Arctic food web, including ice amphipods, polar cod, black guillemots, and glaucous gulls. Samples were collected from an area southeast of Svalbard (Figure 1). From the fish and birds, the liver was taken out and analysed for fifteen individual PFAS as well as a number of traditional hydrophobic POPs, viz. PCBs, the DDT group, and polybrominated diphenylethers (PBDEs, a class of brominated flame retardants). Because of their small size, the whole amphipods were analysed without dissection. Determination of the trophic level of the different species was based on the ra-

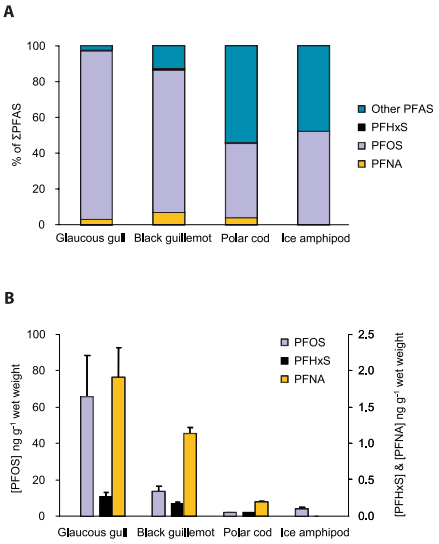

Figure 2. Relative contribution (A) and mean concentrations (B) of PFOS, PFHxS and PFNA in glaucous gull, black guillemot, polar cod and ice amphipod. Error bars are standard error.

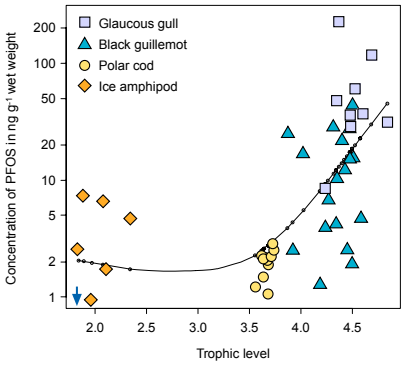

Figure 3. Relationship between concentrations of perfluorooctane sulfonate (PFOS) and trophic level. The trendline follows predicted values of a generalized additive model. The arrow illustrates that one amphipod sample (0.1 ng g^{-1} wet weight concentration) is outside the range of the logarithmically scaled y-axis.

tio of stable nitrogen isotopes (δN15 = $^{15}N/^{14}N$).

Of the fifteen PFAS determined, seven were found in at least one species, but different compounds behave differently in the food web. Three compounds, PFOS, perfluorohexane sulfonate (PFHxS), and perfluorononanoic acid (PFNA), were found in all three vertebrate species in concentrations that clearly increased with increasing trophic level. However, of these only PFOS was found in the amphipods, and the concentrations in the amphipods was slightly higher than the concentrations in the polar cod, the next trophic level in the food web studied (Figure 2). While PFOS, PFHxS, and PFNA contributed to most of the PFAS in the two highest trophic levels, the total PFAS found in the two lowest trophic levels was dominated by other compounds.

PFOS was the only compound that was found in all four species. The relationship between trophic level and PFOS concentration was non-linear (Figure 3). The explanation may lie in that the whole animals were analysed for the amphipods while only the liver was analysed in the other species. There may, of course, also be other explanations in how PFOS is taken up by the individual species. That the trophic level is a major explanatory variable for the concentration of PFAS was clear from a redundancy analysis. On the other hand, comparing the sum of PFAS with the traditional hydrophobic POPs using multivariate statistics showed no correlation, indicating that the uptake/accumulation mechanism may not be the same.

Biological effects of crude oil on sea ice amphipods

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As oil and gas industrial activities are expanding in the Barents Sea, reliable environmental monitoring tools are required to identify the potential impact of toxic chemicals on Arctic biota. Owing to the "zero discharge" policy for the Barents Sea, the main environmental issue of concern is related to accidental discharges caused by production or transport processes. Past studies investigating the biological impact resulting from oil spills in temperate regions have demonstrated that amphipod populations have yet to fully recover; a potential explanation is that amphipods are brooders (the female amphipod carries her young in the brood pouch until they hatch as fully developed immature specimens); hence, pollutants affecting adults will also affect offspring since they are released into the same local environment; furthermore re-colonisation is slow since amphipods do not have pelagic larvae. Considering that the sea ice ecosystem which seasonally covers the Barents Sea is inhabited by amphipods, notably *Gammarus wilkitzkii* (see photo by Erling Svensen), and considering also the lack of studies addressing the long term effect of oil in ice organisms, we have developed a project with three research objectives: 1) to develop facilities and rearing techniques to maintain a population of *Gammarus wilkitzkii* in aquaria with sea ice, and to analyse the reproduction cycle of *Gammarus wilkitzkii*; 2) to investigate the long term biological effect of oil mixed in sea ice on the reproduction cycle of *Gammarus wilkitzkii* (adults, embryos and larvae); 3) to detect effects of oil exposure using a holistic approach spanning from the biochemical level, up to cellular and physiological levels. In addition, aspects of the species' ability to recover from oil spills will also be covered.

Sampling under the ice.
Photo: Bjørn Gulliksen

Gammarus wilkitzkii.
Photo: Erling Svensen

Financed for three years by the Norwegian Research Council under the PROOF program in collaboration with RF-Akvamiljø, the project was initiated this summer with field sampling. The research vessel *Jan Mayen*, commissioned by UNIS, was employed to provide access to the pack ice. Divers sampled the amphi-

pods beneath the ice using hand nets and suction pumps (see photo by Bjørn Gulliksen). Trawling along the ice edge and on the sea bottom was also performed to catch individuals that had sunk to the bottom due to ice drift into the open ocean and ice melting. Animals are now reared at Akvaplan-niva in Tromsø. During the autumn 2005, we have developed an exposure system to simulate the oil contamination resulting from an oil spill; this system is based on the work that was performed by scientists from NOAA-Alaska to study the impact of the Exxon Valdez oil spill. We now intend to expose females carrying eggs to oil for two months and to look at the embryo malformations that could result from the oil exposure.

The oil and gas industries and Norwegian authorities will be provided with answers on the long term impact of oil in the ice on the population of *Gammarus wilkitzkii*. Links between population fitness and responses at lower levels of biological organization (molecular, biochemical, cellular) will be established. These data will help support the development of appropriate risk management systems applicable in sea ice conditions.

Student Silje Haaland from the University of Tromsø processes a multicore sample on deck. The multicore samples are used to investigate the sea bottom environment and the distribution of microfossils. Photo: Nalan Koç

Tracing the flow of Atlantic water to the Arctic Ocean back through time

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In August 2005 the Norwegian Polar Institute's R/V *Lance* set out from Longyearbyen on a three week cruise focusing on marine geology and geophysics. The researchers onboard included Nalan Koç and Dorthe K. Kristensen from the Norwegian Polar Institute, Tine Rasmussen from the University of Tromsø, Tove Nielsen from the University Centre in Svalbard (UNIS) and Liv Plassen from the Norwegian Geological Survey. In addition to the five researchers, ten students from UNIS and the University of Tromsø, two artists from Tromsø and Svalbard and an engineer from the Norwegian Polar Institute participated. The purpose of the cruise was: 1) to collect sea bottom samples to delineate the distribution pattern of present day microfossils and enable monitoring of future changes in the structure of the faunal community and to increase our understanding of the ecological factors controlling the distribution of these organisms; 2) to retrieve sediment cores to investigate the variability of the influx of Atlantic water to the area and changes in sea ice cover around Svalbard during the

past 10,000 years; and 3) to map the sea bottom sediments, in particular sediments deposited by glaciers.

The warm Atlantic Water flows northward along the western and northern margin of Svalbard and into the Arctic Ocean. This water is the main heat source for the Arctic Ocean and is therefore of major importance for the climatic development in this area. One of our research goals is to assess how the inflow of Atlantic Water has varied in the past. We have collected sediments cores from 91 stations to estimate past temperature development of the water masses around Svalbard. Knowledge about past climate changes will enable us to view the present climate development on a longer time perspective. A second goal is to study how Svalbard's glaciers responded (growth/decay) to changes in the flux of Atlantic Water to the area. We have therefore collected marine sediment cores from the northern margin of Svalbard, in the Hinlopenrenna, and south of Nordaustlandet in Erik Eriksenstretet. We shall study the abundance and type of small rock fragments (termed ice rafted debris) in the sediment cores, especially those from Erik Eriksenstretet. These rock fragments are enclosed into the glacier as the glacier erodes the bedrock. When the glaciers calve into the ocean as icebergs the small rock fragments are also transported far out to sea. In our sediment cores we can find and study the small rock fragments that have melted out from the icebergs and been deposited in the sediments. This will tell us how the ice sheet has fluctuated through time.

Past sea temperatures can be estimated by using microfossils (small remains of plant or animal plankton in the sediments) and statistical methods. We have collected many surface bottom sediment samples during the cruise to study the content and distribution of the microfossils, and how they relate to various ecological factors. This will improve the precision with which we can calculate sea temperatures in the past. For this series of samples we have focused especially on Kongsfjorden. Researchers from the Norwegian Polar Institute have initiated a monitoring program for the benthic microfauna of Kongsfjorden as a follow up to this year's cruise in order to study how the microfauna living at the bottom respond to changes in the advection of the warm and saline Atlantic Water into Kongsfjorden. For these studies we aim to utilise the newly established marine laboratory in Ny-Ålesund. We have also applied to the Norwegian Research Council through the FRINAT programme together with colleagues from the University of Tromsø for financial support to carry out this research.

Retrieving the multicore sampling device. Photo: Nalan Koç

The samples we have collected during the cruise will also be part of the MACESIZ (Marine Climate and Ecosystems in the Seasonal Ice Zone) project which is funded through the Norwegian Research Council. One of the aims of this project is to develop and improve methods for reconstruction of the sea ice limit through time.

Interrelationships of crabs, leeches, fish and trypanosomes in coastal waters of northern Norway

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Trypanosoma murmanensis is a blood parasite of marine fish originally described from cod (*Gadus morhua*) in the Barents Sea by Nikitin in 1927, and later found in cod and other fish species off the Atlantic coast of Canada. *T. murmanensis* is capable of killing juvenile cod, especially if the fish is also infected with the gill parasitic copepod *Lernaeocera branchialis*, and heavy trypanosome infections are likely to debilitate adult cod and other fish hosts, making them more vulnerable to predation. The marine leech *Johanssonia arctica* is the only known carrier for this trypanosome. The leech lays its cocoons on the carapace of many crabs, including the red king crab *Paralithodes camtschaticus*, which thus serve as transport hosts for the leeches.

In the 1960s and 1970s, the red king crab was deliberately introduced to the Barents Sea from its native North Pacific. After its introduction, the crab spread and was recorded for the first time in Norway in Varangerfjord, in 1976. The crab population is now spreading westward and southward along the Norwegian coast. It is believed that this may heighten the risk of trypanosome infections in bottom-dwelling fish species by promoting an increase in the population of the leech that carries the trypanosome and thus plays a crucial role in its specific cycle of infection. The purpose of our survey was to search for evidence of this effect.

Our research group has been monitoring trypanosome infections in cod in Finnmark annually since 1999. We found the heaviest trypanosome infections in fish in the Varangerfjord area, where there is a large population of the red king crab, but also in western Finnmark, in the Sørøya area.

We also found that haddock (*Melanogrammus aeglefinus*) were infected at about the same level as cod, but found no trypanosome infections in long rough dab (*Hippoglossoides platessoides*). Recently, we also showed that small cod were more heavily infected than larger cod.

Little was known about the infections in other fish species in the Finnmark area, until a survey in the Autumn of 2002 showed that seven out of eleven fish species were infected with trypanosomes. Again, relatively high infection rates were found in Atlantic cod (highest in Varangerfjord) and haddock (highest in Sørøya), while long rough dab, plaice, lemon sole, halibut and witch were less infected. No infections were found in whiting, deepwater redfish, Norway haddock or Atlantic wolf-fish. The differences in infection between the areas were suggested to be due to the populations of red king crab being newly established in some areas and possibly also due to other trypanosome species being present in western areas around Sørøya.

In the future, the plan is to further explore the differences in trypanosome infection between different fish species from different areas, with the emphasis on differences between northern Norway and western Russia. We will also search for seasonality in the infections. Morphometric studies and DNA analyses of trypanosomes from different fish species will be carried out to confirm the identities of the trypanosomes involved.

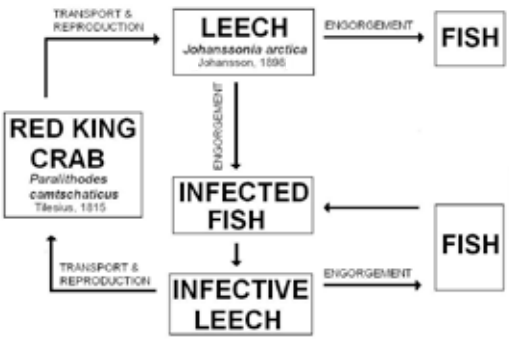
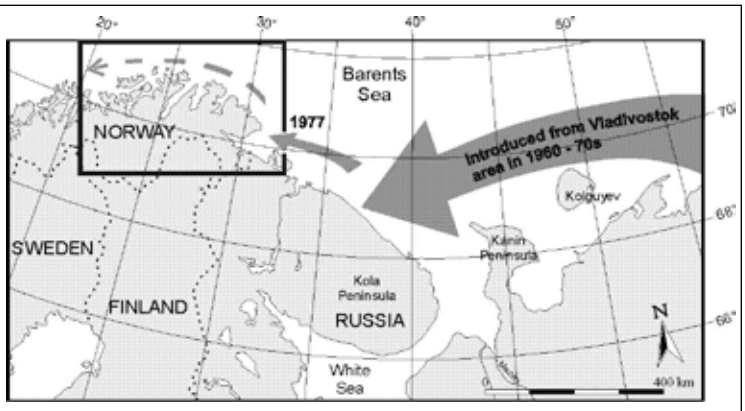


Figure 1. Life cycle of fish trypanosome infection. The leech *Johanssonia arctica* feeds on fish (engorgement). If the fish is infected with *Trypanosoma murmanensis*, the leech becomes a carrier of the infection and when it feeds on other fish it spreads infection among them. The leech uses the carapace of the red king crab (*Paralithodes camtschaticus*) for both reproduction and transport.



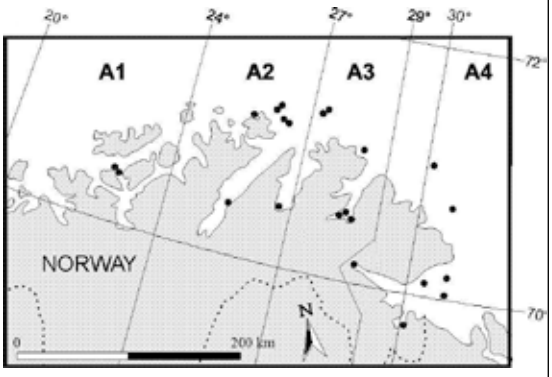


Figure 2. The southern Barents Sea, northern Scandinavia and northwest Russia. (A) Arrows indicate how red king crabs have spread since they were introduced in the 1960s and 1970s. The first reported sighting in Norway was from Varangerfjord in 1976. The area under study is indicated. (B) Closer view of the study area, showing four defined areas. A1, Sørøya; A2, Magerøya; A3, Tanafjord; A4, Varangerfjord. (From Hemmingsen et al. (2005) Mar. Poll. Bull. 50: 336-339.)

Figure 3. Red king crab photographed in captivity. Photo: Ann Kristin Balto

Blood sampling and ringing of kittiwakes on Hornøya, Finnmark.

Immune effects of persistent organic pollutants in Arctic seabirds – method development and ongoing research

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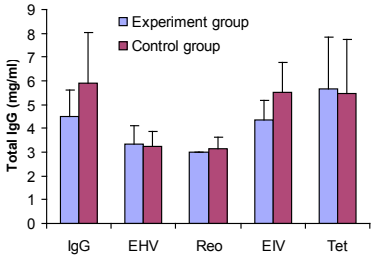
It has been suggested that the high concentrations of persistent organic pollutants (POPs) reported in glaucous gull (Larus hyperboreus) during the last decade may have a negative effect on the health and survival of this species. As a result the glaucous gull has been intensively studied on Bjørnøya in the Barents Sea, and several of the findings support this theory. Positive correlations between nematode intensities and POP concentrations have been seen in glaucous gulls, possibly as a result of immune suppression by POPs. Among wild female glaucous gulls the response to diphtheria toxoid vaccine decreases with increasing concentrations of hexachlorobenzene and oxychlordane. POPs have also been found to be related to decreased reproduction and survival, increased fluctuating asymmetry in wing feathers, decreased feeding effectiveness and reduced levels of thyroid hormones in glaucous gulls.

To test whether these field observations indicate an immune suppressive action of POPs, we performed a study where glaucous gull chicks were fed a controlled diet. The purpose of this study was twofold: 1) to develop methods to measuring parts of the immune system in seabirds and; 2) to test whether the immune system of the glaucous gull was affected by the elevated POP levels. The diet was chosen partly to reflect the natural diet and partly to expose the experimental group to the same mixture of pollutants as in the diet of wild glaucous gulls. In addition to fish, water and vitamins, the experimental group received gull eggs, which mimic the "natural" food found in the marine environment. The control group received hen eggs, which are quite clean.

All chicks were immunized with various vaccines to test their ability to respond to foreign antigens. Antiserum against immunoglobulin G (IgG) in blood from glaucous gull is not available commercially, so we produced our own specific antibodies against IgG. Rabbits were immunized twice with purified IgG from glaucous gulls to achieve "rabbit-anti-glaucous gull IgG" of sufficient strength. This antiserum was used to measure the gulls' IgG. Since the antiserum is general, it gives an estimate of the total amount of this antibody.

The POP concentrations in blood from the experimental group were higher than those in blood from the control group. The concentrations of hexachlorobenzene, DDT, oxy-chlordane and PCBs were three, seven, nine and ten times higher than the corresponding concentrations in the control group. The experimental group produced fewer antibodies against



Total IgG (mg/ml) (p = 0.01) and antibody response after immunization with herpes virus (EHV) (ns), reovirus (Reo) (ns), influenza virus (EIV) (p = 0.005) and tetanus toxoid (Tet) (ns) in the experimental and control group.

influenza virus (p=0.005, figure) and lower levels of total IgG (p=0.01, figure). That the number of antibodies capable of inhibiting viral infection is lower in the experimental group may indicate that the immune system is affected by these POP levels. Rapid production of a sufficient number of protective antibodies against viruses is crucial to fight infections. Our findings suggest that POPs can alter the antibody production on a general basis. It is therefore reasonable to assume that exposure to POPs at this level is associated with decreased resistance to infections and that this could be serious for the glaucous gull's health. The observed lower levels of IgG and the reduced ability to produce antibodies after vaccination in the group with elevated POP levels mirror the findings in polar bear (*Ursus maritimus*).

The glaucous gull is an apex predatory and scavenging seabird in the Arctic, which accumulates high levels of POPs. To determine effects on the immune system, we propose to study puffin (*Fratercula arctica*) and kittiwake (*Rissa tridactyla*). These seabird species forage at a lower level in the food chain and therefore have lower levels of contaminants than the glaucous gull. Screening studies have shown that puffins have about twice as much PCB and DDT as kittiwakes and about half as much as glaucous gulls. Our study of these three seabird species will give us an opportunity to evaluate the immune effects of the POP cocktail actually found in the Barents Sea.

Icy future for Svalbard reindeer?

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Female Svalbard reindeer searching for food in October. Photo: Ronny Aanes

It is now widely accepted that the Earth is undergoing warming. Climate models predict that this warming both will be more pronounced, and will occur earlier, in the Arctic, compared to the global average. Arctic ecosystems may thus serve as reference areas for studies relating expected ecological effects to a changing climate.

CAFF (Conservation of Arctic Flora and Fauna) has suggested that reindeer would be a useful circumpolar indicator species for the environmental state of health. Long-term monitoring of reindeer may thus play a vital role in documenting Arctic environmental changes, as it is possible to gain a mechanistic understanding of the causes of variation in the sizes of animal populations.

For example, studies on Svalbard reindeer have been used to examine the effects of climate variation on the population dynamics of the only large herbivore on Svalbard. Our research has shown that several factors (e.g. population density dependence and local and regional climate variations during summer and winter) operate in concert on Svalbard reindeer population growth rate. One common finding in these studies is that the environmental conditions during winter strongly affect the population dynamics.

An important challenge for ecologists studying biological effects of climate change is to predict future consequences of a changing climate. One factor that may come to play a key role for reindeer in the Arctic future is changes in the amounts of winter ground-ice (see Figure 1a, 1b). Whereas snow depth is an extensively documented factor that may negatively affect large herbivore population growth rate in Arctic and sub-Arctic areas, the effect of ground-icing is a less studied phenomenon. Some observations have shown that ground-icing is a potentially dramatic factor: extensive icing can result in mass die-offs of large herbivores, as it can effectively prevent access to food. An example of this already exists from a re-introduced population of Svalbard reindeer; in the autumn of 1993, extreme amounts of rain fell on Brøg-

Figure 1.
a) Picture shows more than 25 cm thick ground-ice blocking reindeer forage on Brøggerhalvøya. The ground-ice was formed by freezing rain falling on ground colder than 0 °C.
b) Ground-ice on ridges on Brøggerhalvøya. Such ridges are usually free of ground-ice and are popular feeding sites for reindeer when deep snow or ground-ice prevent access to food other places.

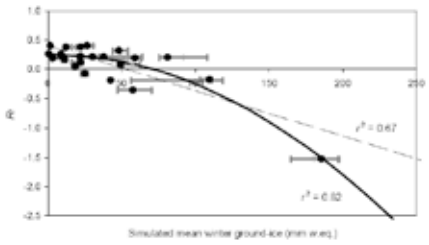

Figure 2.
The relationship between modelled mean annual winter ground-ice thickness and Svalbard reindeer population growth rate, Rt. The population growth rate, Rt, is defined as: ln(Nt+1/Nt), where ln is the natural logarithm, and Nt is population size (number of individuals) in time t.

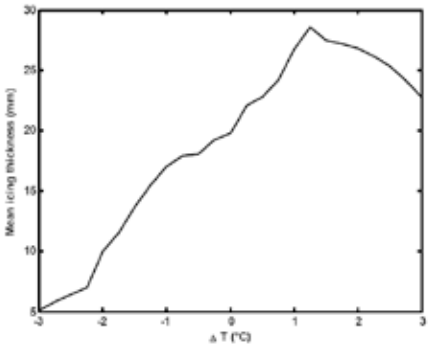

Figure 3.
Mean over the period 1970-2002 of the modelled winter ground-ice thickness, as a function of the temperature difference added to the original input temperature record used in the model (Kohler and Aanes, 2004). $\Delta T = 0$ represents the current situation.

gerhalvøya while the air temperature fluctuated between warm and cold. This resulted in a thick layer of ground-ice over most of the feeding areas. The population crashed with a nearly 80% reduction in population size due to a combination of high mortality and migration to other areas.

Recently, we quantified the impact of snow and ground-ice on the Svalbard reindeer population dynamics using a simple snowpack model driven by records of temperature and precipitation as input parameters. We found that the amounts of ground-ice indeed can explain a significant amount of the variability in the Svalbard reindeer population growth rate (Figure 2).

In an attempt to examine what might happen in a future climate, we take the simple approach of modifying input to the model by adding or subtracting a certain number of degrees (°C) from the entire temperature record. For each model run, the resultant record of ground-ice thickness covering the period 1969-2002 is averaged to form a mean ground-ice thickness, which now becomes a function of the temperature difference added in the observation period (Figure 3). This approach, while relatively crude, nonetheless shows quantitatively what we would predict qualitatively. In a colder climate we would get less ground-ice compared to the current situation, since there would be fewer warm events during the winter. Conversely, warmer winters will bring increasing amounts of ice on the ground, until a certain threshold temperature is reached; beyond this point, the amounts of ground-ice decrease. The latter is coupled to increased melting offsetting the formation of new ice. If the form of the curve in Figure 3 is valid, then only a slight increase in winter temperature would likely have large effects on the Svalbard reindeer population dynamics.

Although this gives a quick glance into the future it is an extremely simplified view, as we held everything else in the model constant (e.g. precipitation). More realistic studies extending this simple approach would be of great value in trying to forecast biological effects of climate change. The next step would be to implement more realistic parameters (e.g. changes in precipitation patterns) in the snowpack model. Also, data on the effects of climatic variation on other components within the Svalbard ecosystem that may affect reindeer would be a significant contribution. This will hopefully enable us to model the potential impact of future icing on the dynamics of Svalbard reindeer with greater precision.

For more information, see Kohler and Aanes "Effect of winter snow and ground-icing on a Svalbard reindeer population: results of a simple snowpack model" published in Arctic, Antarctic and Alpine Research, Volume 36, pages 333-341.

Long-term effects of military training on the environment in Troms county

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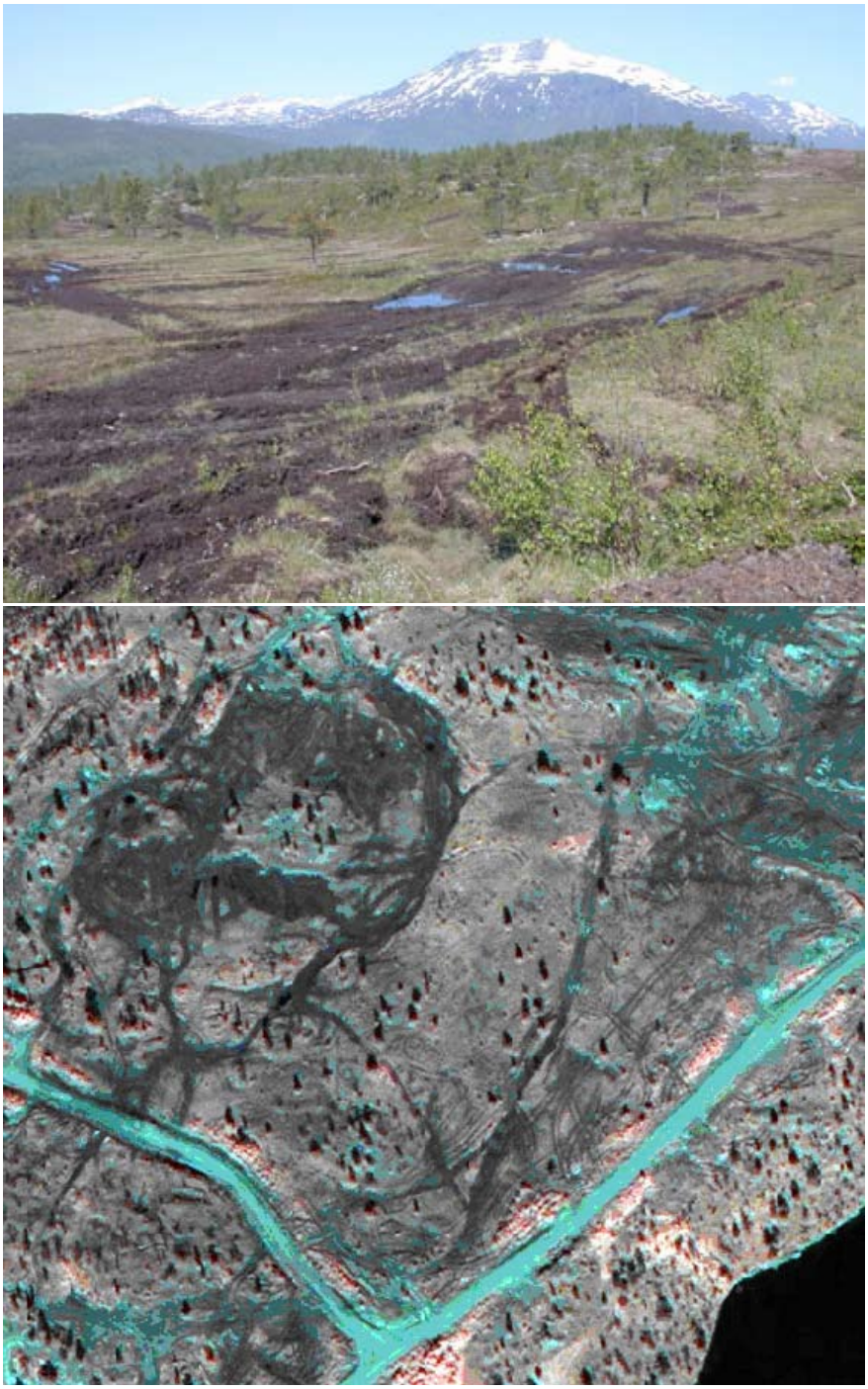
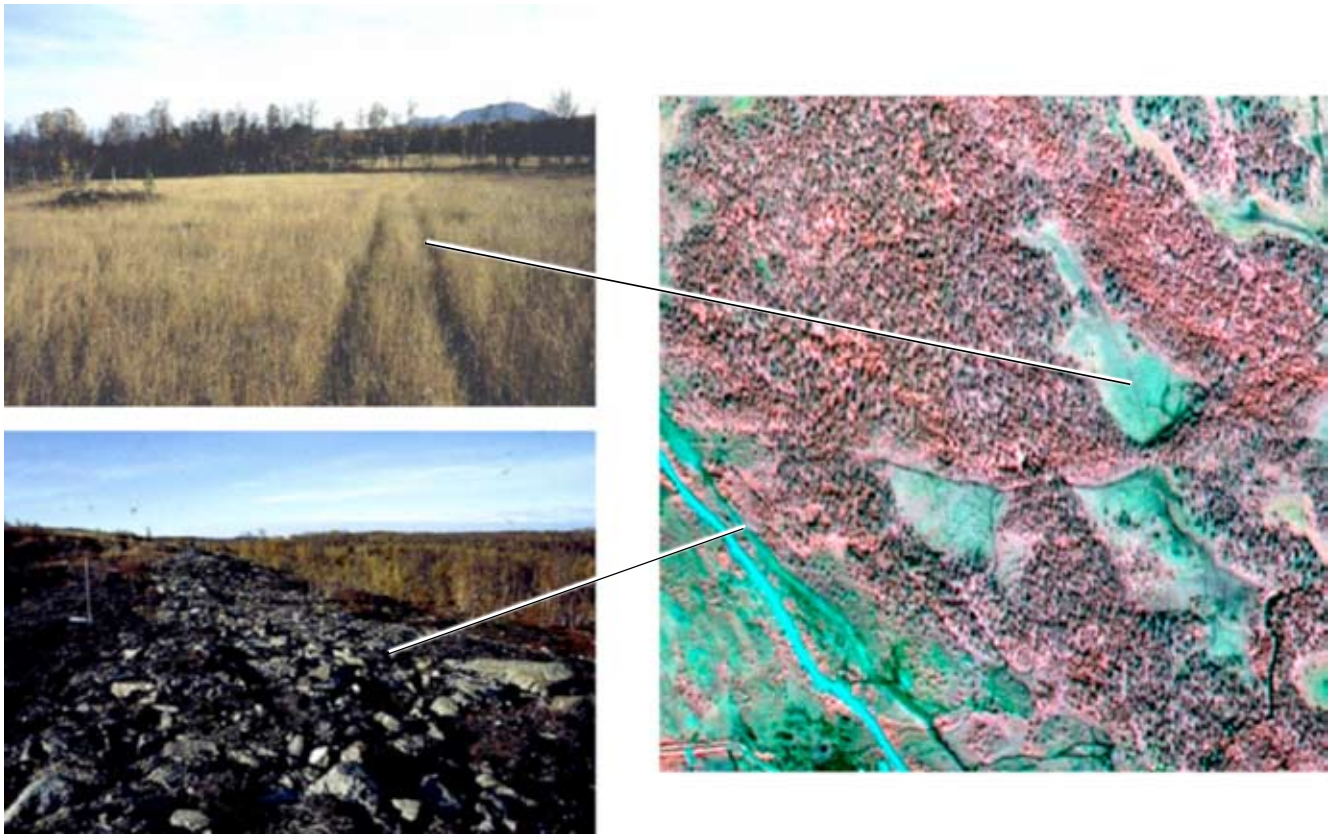
Use of heavy all-terrain vehicles (ATVs) in vulnerable environments may cause lasting damage. The main objective of this project was to document and assess the long-term effects of military training on the environment and biodiversity within Troms and northern Nordland counties, an area of approximately 9380 km^2. The project investigated geology and technical vulnerability, studied vegetation in military battlefields, mapped terrain damage inside and outside military battlefields and studied its effect on the avian and mammalian fauna, and assessed the effects on biodiversity. Finally, we make recommendations for preventive and remedial (restoration) actions for further military training activities.

The total amount of damage, including areas of infrastructure and zones of influence, has been mapped and documented in field work and by use of high resolution satellite and aerial imagery. The length of the ATV tracks in the three main military battlefield areas, Blåtind, Mauken and Setermoen, was estimated to more than 1000 km. With a zone of influence of 50 m along the tracks, the area damaged or influenced was estimated to cover 56 km^2 (17%) of a total area of 334 km^2. Infrastructure elements (artillery and gun stands, buildings, roads) were estimated to cover 8.5 km^2, giving a total influenced area of 19% within the main battlefield areas. An additional 245 km of ATV tracks, infrastructure and damage outside the main battlefield areas covered 5 km^2. The total area of damage and influence within the study area was estimated to 70 km^2.



Tracks caused by heavy armoured vehicles in the Setermoen battlefield detected by the Quickbird satellite. Upper photo: Hans Tømmervik. Lower photo: Copyright Digital Globe (Quickbird satellite)

Effects on vegetation were assessed using satellite-based vegetation cover maps. Mire vegetation was the category most damaged or influenced, and showed an extensive



Single track from an ATV (6-wheeled motorcycle) in a mire can be seen in the IKONOS-2 satellite image. A road under construction is also visible. Left photos: Erland Loso. Right photo: Copyright Space Imaging (IKONOS-2)

network of ATV tracks. The regional investigation showed tracks also on mountain heaths and ridges, but the damage was not as distinct as in the mires. The damage to mire vegetation was largest in Mauken and Setermoen; mires in Blåtind were less damaged. In mire vegetation, moss species decreased within the ATV tracks. The traffic has led to a transformation from typical mire and fen vegetation (drier conditions) to a carpet and mud bottom dominated vegetation influenced by high water levels. In other environments the number of species was unchanged, but lichen species decreased and moss species increased. The number of typical climax species was reduced and pioneer species (grasses and mosses) dominated within the tracks and damaged areas. The effect on biodiversity was large in areas with thin soils above the bedrock, and the tracks and wear in these areas were clearly visible.

The density of nesting waders in mires and wet areas influenced or damaged by ATV traffic within military battlefield areas was detectably dissimilar from that in control areas outside. These dissimilarities are likely to be effects of the ATV tracks and of the disturbances this traffic has caused waders during the breeding season. The small mammal population had crashed shortly before the project, so the effects of the military activity could not reliably be assessed. However, these activities could have had negative effects on the small mammal populations locally, especially in mire and mountain habitats. Effects on the small mammal population on a larger and regional scale are not likely because of the limited area which is influenced.

An evaluation showed that remedial actions taken by the military had a good effect on the environment. After two years, restored ATV tracks showed a vegetation fraction of 80% while unrepaired tracks only had 45%. Most of the remedial actions were taken in wet areas like mires, which shows that the military already has a well functioning remedial action plan.

Canalization of traffic from more sensitive to less sensitive areas is the most important preventive action recommended. Biodiversity maps and technical sensitivity maps are good tools for planning exercises and managing the military shooting ranges and exercise fields. Our report also gives advice on management, preventive and remedial actions for further training activities.

The project's main conclusion is that military activities have significantly influenced the environment and biodiversity in Troms, but the damage is local and of little importance for the study area as a whole.

This investigation gives a good background for assessing the effects of military activities within the study area, and has contributed by visualising the need for preventive and remedial actions. The design and the results also make a good starting point for detailed monitoring of future effects of military activity within the shooting ranges and exercise areas.

For more information, see Tømmervik et al. 2005. Long-term effects of military training on the nature environment in Troms County. NINA Report. 230 pp.

Greenland halibut – a fish with fewer secrets

Recent research has changed the perception of the species' behaviour and biology, and given new directions to research and stock assessments

The Institute of Marine Research, an agency under the Norwegian Ministry of Fisheries, carries out scientific studies on marine resources, with a special focus on the Norwegian coastal zone and the adjacent seas. Its most important tasks are to provide sound scientific advice to the authorities, industry and the general public, and to foster cooperation in research and resources management.

In this article, we present one of the projects currently ongoing at the Institute's Tromsø branch.

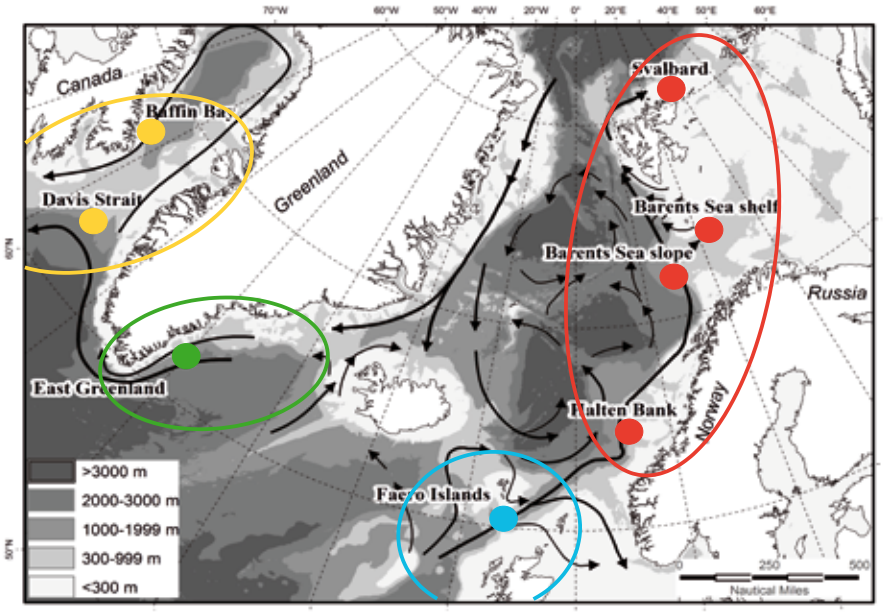
Greenland halibut

The Greenland halibut is a valuable fish, but also something of a puzzle. For years scientists have struggled to produce sound management advice based on data known to be uncertain. Are the populations of Greenland halibut in the North Atlantic distinct, or do they mix? Why are the age distributions so inconsistent? Is bottom trawling really a suitable method for sampling this species? And is it really a round flatfish? Maybe it's a flat round fish…?

To answer these and other questions about the Northeast Arctic Greenland halibut, a three-year Russian-Norwegian research program was initiated in 2002 between the Institute of Marine Research and PINRO. The results have clarified many of the questions we had, and form the basis for a new three-year programme starting in 2006. Here we briefly present some preliminary results of particular relevance for stock evaluations.

A genetically distinct population

Our work focused on the Northeast Arctic stock, pragmatically defined as the entity exploited in the Barents Sea and adjacent slope areas. Previous accounts hinted at migratory links with other areas, i.e. drift of spawning products towards East Greenland and migration of adults from Iceland to the Barents Sea. Our analyses of 6000 gene samples from eight North Atlantic localities showed that Greenland halibut from Halten Bank to Svalbard belong to one genetically homogeneous population that differed significantly from those in other areas. Thus, the Northeast Arctic stock seems to be a well defined population with little exchange with neighbouring stocks.



Populations of Greenland halibut in the North Atlantic. Genetic analysis confirms that the Northeast Arctic stock (red) is a separate population.

Russian juveniles and Norwegian adults

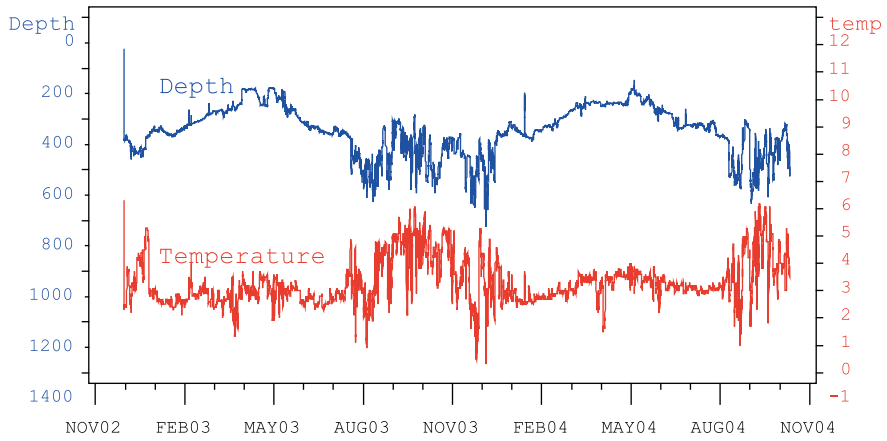
Surveys from Svalbard to Franz Josef Land showed a high proportion of juveniles in the Russian EEZ. Older, larger fish were found farther south and west. In late summer 2004 and 2005 Russian and Norwegian research vessels and commercial trawlers investigated most of the Barents Sea and the Svalbard area as well as the deeper areas from 62 to 80 N, thus covering most of the distribution area of the Northeast Arctic stock. From these surveys we estimate that 89-94% of the biomass (but only 62-82% of the population) is in the Norwegian EEZ and the Svalbard zone combined.

It's a slow-growing, not a fast-growing fish

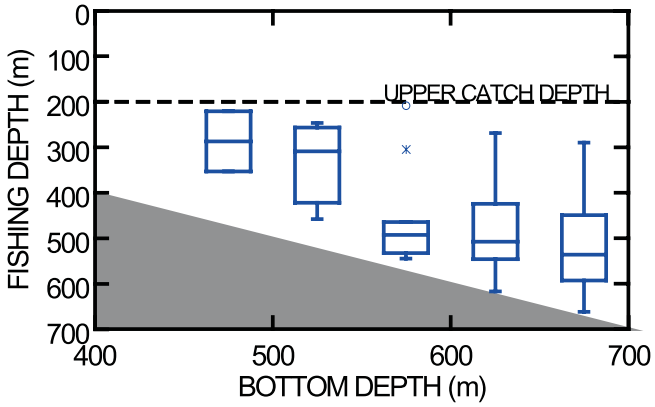
Greenland halibut used to be considered one of the most fast-growing flatfishes, but this estimate was based on extrapolations of the growth of the youngest age groups. We found adults grow much more slowly than previously believed. Data from tagged, recaptured Greenland halibut show a mean annual length increment of 2.0 cm, decreasing from 2.3 cm for 40-49 cm fish to 1.2 cm for fish above 70 cm.

Refined ageings make them twice as old

The method currently used to determine the age of the fish is not scientifically sound and underestimates the age of older individuals. We have developed a refined ageing method using digital photography that makes interpretations available for analyses. The method was validated by use of signal analyses and the estimates agree well with other data, e.g. from tag-recaptures and radiocarbon anal-



Archival tag recording from a single Greenland halibut that was at large nearly two years. Note the sharp transition between behaviour patterns and the repeated annual cycle.



Bathymetric distribution of pelagic catches of adult Greenland halibut. The whole water column was fished with vertical long-lines, but Greenland halibut was only caught deeper than 200 m depth.

yses. Our next goal is to further refine the ageing method and apply it in annual assessments of the Northeast Arctic Greenland halibut stock.

Video recordings answer many questions

Most previous research on how flatfish react to an approaching trawl has been done in shallow water and in daylight. These results may not be directly relevant for Greenland halibut living at low light levels below 500 m depth. We therefore studied how these fish behave in their natural environment by use of video and flash-photo recordings as well as trawl experiments with auxiliary bags. All Greenland halibut we saw were either lying on the bottom or swimming in a horizontal position near the bottom, and showed no tendency to schooling. A method was developed to automatically estimate fish length, swimming speed and direction, and analyses revealed the fish reaction towards an approaching trawl, the effect of using artificial light, the length-dependent catchability of the sampling trawl, as well as a surprise effect increasing catchability during the first few hundred meters of the trawl path.

Also adults go pelagic

Adult Greenland halibut are considered to be bottom dwellers, and previous studies have found only 1 and 2 year old individuals swimming pelagically. However, our experiments with vertical longlines show individuals in large parts of the water column. Adult Greenland halibut were found pelagically throughout the year, and over all bottom depths investigated, even over depths where the species is not found at the bottom. Individuals were caught as high as 600 m off bottom, but not above 200 m depth. This upper limit was independent of bottom depth and varied between seasons, from 400-500 m in March and August, to 250 m in November. Males predominated in the water column and females on the bottom. During spawning season (November), only males were caught pelagically.

The vertical activity of individual fish, as recorded by archival tags, varied markedly with season, with much more vertical movements during summer and autumn than during winter and spring.

The pelagic behaviour of Greenland halibut may influence the annual bottom trawl surveys, as parts of the population are out of the gear's range. To improve population estimates, the pelagic occurrence of the Greenland halibut needs to be quantified.

Future research

The Russian-Norwegian research program has given important new insights into Greenland halibut biology and behaviour and helped identify the most important remaining problems before reliable stock assessments may be achieved. The Tromsø department of the Institute of Marine Research will continue to focus on these questions, in cooperation with the University of Tromsø and Russian scientists at PINRO.

Key topics for future research are:

1) Further validation and implementation of an accurate and precise ageing method.
2) Quantification of pelagically occurring Greenland halibut and the dynamics of pelagic excursions.
3) Combination of survey data from different sampling trawls relative to the size and population composition of Greenland halibut.
4) Development of sound stock assessment methodology and a sustainable harvest strategy.

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Year-round in Antarctica

In February, Queen Sonja inaugurated a new phase for Norway's Antarctic research station "Troll", now rebuilt and expanded to enable research year-round. The Norwegian Polar Institute (NPI) is responsible for the station, but several other institutes also carry out research there. The Norwegian Institute for Air Research has already initiated a project to measure UV radiation and some key pollutants, and a comprehensive environmental pollutant and greenhouse gas monitoring programme is planned. Scientists from NPI will be studying glaciers and bird colonies. Kongsberg Satellite Services, headquartered in Tromsø, is building a ground station at Troll. The new satellite receiving antenna will complement those already operating in Svalbard, making it possible to download data twice every time a satellite orbits the earth, instead of just once. Among other things, this will provide the world's weather services with fresher data and may lead to more accurate weather forecasts. It will also facilitate comparisons between data from northern and southern polar areas.

Royal visitors

One hundred years ago, Prince Albert I of Monaco played an important role in the early days of Norwegian polar research by supporting expeditions to northwestern Svalbard. Prince Albert's role was not merely that of financier. A trained oceanographer, he participated actively in the research, charting much of Krossfjorden. The expedition is considered a direct forerunner of the Norwegian Polar Institute and included many of the people who later became central figures there. The party did the first thorough geological, topographic, botanical, and meteorological studies of this part of Svalbard. Detailed maps were also made. Memories of the expeditions are indelibly inscribed on the landscape: many geographic features bear names related to Prince Albert I, his family, his country, and his companions.

In late July, his great-great-grandson Prince Albert II paid a private visit to Svalbard to see the places that had made such a deep impression on his ancestor. Visiting Ny-Ålesund, Albert II heard scientists from the Polar Environmental Centre lecture on climate change and environmental pollution. The Prince and his contingent were knowledgeable and interested listeners and the ensuing discussions were lively.

Queen Sonja officially opens Troll as a year-round station by placing a globe of ice from a Norwegian glacier among the Antarctic rocks. The ice sculpture was a gift from the Directorate of Public Construction and Property, here represented by Øivind Christoffersen. The sculpture is expected to survive for many years in the constant sub-zero temperatures at the site. Photo: Einar Johansen.

On February 9, King Harald V opened the exhibition "The White Adventure – Polar Norway 2005" at Tromsø Museum. Part of Norway's Centennial Anniversary 1905-2005, the exhibition was put together by the University of Tromsø in collaboration with the Norwegian Polar Institute, the Polar Museum in Tromsø and the Regional State Archive of Tromsø. It examines Norway's identity as a polar nation and its past and present activities at both poles. Later in the year, a touring version of the exhibition requisitioned by the Ministry of Foreign Affairs went on the road. After first stops in Murmansk and Washington, it will travel to major cities all around the world, and during the Torino Olympics it will be on display in nearby Savona.

In February, King Harald also opened "Teorifagbygget" at the University of Tromsø. This complex of six linked buildings is home to several departments and the Centre for Sámi Studies, as well as auditoriums, reading

Prince Albert II of Monaco in Ny-Ålesund, with his hosts Kim Holmén, Senior Scientist at the Norwegian Institute for Air Research (left) and Geir Wing Gabrielsen, Research Programme Leader at the Norwegian Polar Institute (right). In November, Holmén moved to NPI, where he is now Research Director.

rooms, libraries and restaurants. About 4000 students are expected to use the building on a daily basis.

Queen Sonja visited the Norwegian Polar Institute and Polaria Visitors' Centre in August. Polaria's seals were a real hit. Unintimidated by royalty, the bearded seal Sassen gave the Queen a kiss on the cheek. Visiting NPI once more in November, Queen Sonja was shown around the library and examined one of its real treasures: Gerrit de Veer's account of Willem Barents' discoveries in the far North, printed in 1598. Later she heard lectures on climate change, the upcoming International Polar Year, and management plans for the Barents Sea region.

New Research Schools

The board of the University of Tromsø has decided to establish another two Research Schools with an Arctic profile, bringing the total to three. The Research Schools provide a formal framework for PhD students in prioritised fields of science, and are given extra resources in the form of PhD student scholarships and post-doctoral positions.

The three northern Research Schools are: ARCTic Marine EcOSystem Research network (ARCTOS), a cooperative effort between the University of Tromsø, NPI, Akvaplan-niva, and the University Centre in Svalbard (UNIS); Arctic Marine Geology and Geophysics, a cooperative effort between the University of Tromsø, the Geological Survey of Norway, the Norwegian Polar Institute, and UNIS; and Citizenship, Encounters and Place Enactment in the North (CEPIN).

Nansen award

Professor Tore O. Vorren, dean at the Faculty of Science, University of Tromsø, received the Nansen Award on October 10. The prize is awarded by the Board of the University of Oslo. In their motivation, the committee cited Prof. Vorren's three decades as a driving force in national and international Arctic research. "Together with colleagues and students, he has made important contributions to the understanding of climatic history from the last ice age and up to the present."

In connection with the ceremony, University of Tromsø Professor Asgeir Brekke – Nansen Award laureate in 2003 – presented the "Nansen Memorial Lecture", and was also awarded the Nansen medal.

Marbank and Marbio open

Norway's new archive of marine organisms, Marbank, was officially opened in Tromsø on October 20. Co-located with the "bank" is the analysis platform, Marbio. Together, the new facilities will provide an important platform for the registration and exploration of bioactive compounds in marine organisms, and will hopefully be a useful tool in the effort to develop new drugs aimed at fighting bacteria, viruses, inflammation and cancer. Marbio and Marbank were established as a joint venture by the University of Tromsø, the Institute of Marine Research, the Norwegian Institute of Fisheries and Aquaculture Research, and the Norwegian Polar Institute.

Polar Conference 2005

The first annual Polar Conference in Tromsø was arranged on February 8. The topic of this year's conference was Norwegian research activity and energy exploration in the polar region. In a separate section, invited speakers gave a historical and international perspective on Norway as a polar research

EISCAT antenna in Svalbard. Photo: Inger Lise Næss

nation as well as on future challenges facing Norwegian polar research.

New EISCAT members

The EISCAT (European Incoherent SCATter) organisation operates radar systems used to study phenomena in the magnetosphere and ionosphere. During the EISCAT Council Meeting held in Qingdao in October, Director Dong from the Chinese Research Institute of Radiowave Propagation signed the EISCAT Agreement on behalf of China. China will enter the EISCAT organisation as an associate member from 2006 and become a full member from 2007. The Ukrainian National Academy of Sciences signed a Declaration of Intent in November, implying that the Ukraine intends to join EISCAT from 2008.

Change of the guard at the Norwegian Polar Institute

This summer, Olav Orheim retired as Director after many years at NPI. He joined the permanent staff of the Institute in 1972 with the task of coordinating work in Antarctica. Though he has now left NPI, Orheim continues to work with polar issues as Secretary of the committee coordinating Norway's activities during the upcoming International Polar Year 2007-2008. Orheim is succeeded as Director of NPI by Jan-Gunnar Winther, previously Head of Antarctic Research and Research Director at the Institute.

Distinguished guest

Academician Nikolai Laverov, Vice President of the Russian Academy of Sciences, visited Tromsø in mid-August, hosted by the University of Tromsø and the Polar Environmental Centre, along with representatives from the Polar Committee of the Research Council of Norway. The aim of the meeting was to stimulate research collaboration between Russia and Norway, particularly in the High North. Key issues for cooperative research include climate, technology, oil exploitation and radioactivity, and the environmental challenges they pose. A follow-up meeting is planned for the winter of 2005-2006.

Books and maps

In December 2004, the third and last volume of "Norsk polarhistorie" was presented to the public. This three-volume series takes a deeper look at Norway's long history of activities in polar areas. The first volume focuses on expeditions; the second on research. The final volume deals with the importance of the polar regions in Norway's economy, from the early days of sealing and whaling, through winter pelt-hunting, fishing and mining to the latest development: mass tourism. Editors are Einar-Arne Drivenes and Harald Dag Jølle, of the University of Tromsø. Work is underway to produce a one-volume edition in English.

Also in December 2004, Tromsø Museum released a new issue of its periodical Ottar, which focused on Bjørnøya. The informative, beautifully illustrated booklet contains contributions from scientists working at the Polar Environmental Centre, the University of Tromsø and the Norwegian Polar Institute among others.

What should you do if you encounter a polar bear? Whatever the rumours may say, this is not going to happen in Tromsø. But in Svalbard the risk of meeting a polar bear must always be borne in mind. To advise and inform both visitors and residents, the Norwegian Polar Institute has published a brochure called "Polar Bears in Svalbard". It can be downloaded from the website of the Governor of Svalbard (www.sysselmannen.no/eng) under Brochures.

Svalbard is a geologist's dream because there is little vegetation to hide what geologists are most eager to see, namely the rocks. Geology enthusiasts may want to check out Norwegian Polar Institute's new map of Billefjorden, an interesting area not far from Longyearbyen. In addition to showing the area's geology, the map provides an excursion guide, colour photos and information of general interest.

Armchair geologists might prefer an interactive web-based map of the Quaternary geology of Adventdalen and Jan Mayen, available at http://kart.npolar.no/website/qAdvent.

For the historically inclined, there are reproductions of five Dutch maps from the seventeenth century. The originals belong to the extensive collection of historic maps housed at the Norwegian Polar Institute's library.

Doctorates in polar studies at the University of Tromsø

Dr. art.

Marianne N. Soleim

Sovjetiske krigsfanger i Norge 1941-1945 – antall, organisering og repatriering
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Dr. scient.

Bjørn Lindberg

Cold-water coral reefs on the Norwegian shelf – acoustic signature, geological, geomorphological and environmental setting (2004)
bjorn.lindberg@ig.uit.no

Vedad Hadziavdic

Time series analysis of physical properties of complex plasma crystals
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Kirstin Janssen

On the genetics, ecology and evolution of colour polymorphism. A study of the arctic skua (*Stercorarius parasiticus*)
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Stein Rune Karlsen

New methods for bioclimatic mapping of arctic, alpine, and boreal areas.
stein-rune.karlsen@itek.norut.no

Bjørn Krafft

Population biology of ringed seals (*Pusa hispida*) in Svalbard, Norway (joint supervision with the Norwegian Polar Institute)
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Ståle Liljedal

Factors influencing sperm production, sperm competition and male fertilization success in the Arctic charr, *Salvenius alpinus*
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Tuula Sarvas

The Pan I locus and population structure of cod (*Gadus morhua* L.) in Norway
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PhD

Carolin E. Arndt

Ecosystem dynamics in arctic sea ice: the impact of physical and biological processes on the occurrence and distribution of sympagic amphipods
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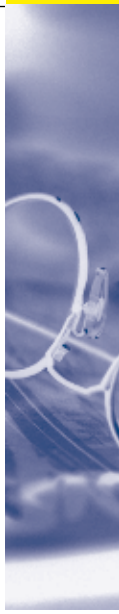

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