

# Fram Forum

FRAM – High North Research Centre for Climate and the Environment

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# 2020



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Photo: ARCTOS

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Photo: Pierre Blévin

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Photo: National Library of Norway

**DRIFTING WITH ICE – FROM THE SCHOONER FRAM TO ULTRAMODERN RV POLARSTERN** The MOSAiC expedition is following Nansen's example in the Arctic Ocean. In this Retrospective article, **Ellen Kathrine Bludd** highlights similarities and differences. *Page 108*

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## RAISING THE IMPACT OF FRAM CENTRE RESEARCH

In September 2018, the Ministry of Climate and Environment and the Research Council of Norway initiated an evaluation of the Fram Centre. A nine-member evaluation committee of international experts from various disciplines was tasked with assessing how effectively the Centre produces and disseminates knowledge to support management of natural and cultural resources in the High North.

Their report, presented in May 2019, finds that the Fram Centre is producing high quality, relevant research. Fram Centre researchers publish a multitude of articles each year, frequently in highly regarded international journals. This knowledge informs policymaking and resource management at both national and international levels. Closer to home, however, the Fram Centre's communication with the community and stakeholders is described as one-sided.

The Fram Centre Flagship programmes have ambitious plans for outreach and dissemination, and some of the articles in this issue of Fram Forum describe innovative communication strategies (such as using culture for scientific outreach, see page 134). Nonetheless, the evaluation's criticism appears valid: the researchers generally present their results after the work is completed, without necessarily engaging the public in dialogue.

“An interesting finding was that quite often outreach was seen as the equivalent of impact, i.e. if you had published and disseminated the research results you had also created impact. The committee sees this as an oversimplification.”

A lack of citizen involvement in determining the Centre's research priorities is a recurring theme in the evaluation. Another is that input from social scientists did not come early enough in the process.

“Social science is not [...] sufficiently included in shaping of programmes and design of research questions.”

Projects do not become truly interdisciplinary simply because both social and natural scientists are included in the research teams. There are obstacles to overcome. Social and natural sciences do not ask the same types of questions; they use different vocabularies and apply different research methods. These two disparate research cultures appear to be struggling to find ways to work together fruitfully. Perhaps it would help if each discipline acknowledged the other's strengths.

New knowledge and new technologies are often developed without stakeholder involvement. But scientific conclusions always involve uncertainties, and innovations pose unknown risks. How does society understand uncertainty and risks? How might society react to and handle these unknowns?

Let's take an example. Climate change is complex issue, teeming with uncertainties and risks. Dealing with its consequences will require major changes in society - how we produce our food, where we live, how we get from one place to another, how we construct our homes and keep them warm (or cool). Such far-reaching changes cannot be achieved without broad societal engagement.

This is one context where the unique strengths of the social sciences can be brought to bear. Social scientists can assess the socioeconomic costs of climate-induced changes, elucidate the value of ecosystem services, and provide insight into people's attitudes toward potential problems and proposed solutions.

If the social sciences are fully integrated into project planning and execution; if communities are engaged in setting research priorities; if citizens more readily embrace research outcomes and act on recommendations - then the Fram Centre's research can truly create impact.

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Janet Holmén, *Editor*



## GOLDEN PLOVER

After a lifetime of fieldwork in the mountains, the golden plover has become a dear friend and companion. My work takes me from the coastal moorlands and mountains of central Norway to eastern Finnmark, and the plover is a quintessential part of my spring and summer. To a lonely wanderer, it offers companionship, but also some frustration. Its wistful call seems to follow you throughout the long day.

In the nesting season, a golden plover will often appear and keep a close watch as you cross its expansive territory. At some point, the neighbouring plover will take over and follow you to the next territorial boundary, where yet another plover will step in.

The wanderer sometimes feels as if the same golden plover has been along for an entire day's trek, a delightful companion, but an exasperating one.

*Text and photo: Geir Vie*

**Publisher**  
Framsenteret AS

**Editor**  
Janet Holmén  
Freelance editor  
// [alchemia@online.no](mailto:alchemia@online.no)

**Executive**  
Helge M Markusson  
Outreach coordinator  
Fram Centre  
// [helge.markusson@framsenteret.no](mailto:helge.markusson@framsenteret.no)

### Editorial committee

Ellen Kathrine Bludd  
UiT The Arctic University of Norway  
// [ellen.kathrine.bludd@uit.no](mailto:ellen.kathrine.bludd@uit.no)

Trude Borch  
Akvaplan.niva  
// [trude.borch@akvaplan.niva.no](mailto:trude.borch@akvaplan.niva.no)

Cathrine Henaug  
NINA Norwegian Institute for Nature Research  
// [cathrine.henaug@nina.no](mailto:cathrine.henaug@nina.no)

Elin Vinje Jenssen  
Norwegian Polar Institute  
// [elin.vinje.jenssen@npolar.no](mailto:elin.vinje.jenssen@npolar.no)

Eva Therese Jenssen  
University Centre in Svalbard  
// [eva.therese.jenssen@unis.no](mailto:eva.therese.jenssen@unis.no)

Christine F Solbakken  
NILU – Norwegian Institute for Air Research  
// [christine.solbakken@nilu.no](mailto:christine.solbakken@nilu.no)

Gunnar Sætra/Stine Hommedal  
Institute of Marine Research  
// [stine.hommedal@hi.no](mailto:stine.hommedal@hi.no)

**Layout**  
TANK Design Tromsø AS  
[www.tank.no](http://www.tank.no)

**Printer**  
Interface Media AS

**Online version**  
[www.framforum.com](http://www.framforum.com)

**Contact information**  
FRAM Forum  
Fram Centre  
POB 6606 Langnes, N-9296 Tromsø  
NORWAY

[www.framcentre.com](http://www.framcentre.com)  
[post@framsenteret.no](mailto:post@framsenteret.no)  
Phone: +47-7775 0200



Christine Kristoffersen Hansen

# Arctic giant on the lookout for adventure

PROFILE

Salve Dahle is inspired by the past, driven by the future, and lives for the pursuit of the unknown.





Photo: Ingun A Mæhlum

**I** SHOULD PROBABLY START CLEARING OUT HERE. I've actually fetched a rubbish bag, but I haven't got around to using it yet."

Salve Dahle walks through his corner office in the Fram Centre. Between stacks of books and piles of papers, newspaper clippings and brochures. A stuffed common guillemot collected at the nuclear testing site at Novaya Zemlya dangles upside down at the end of a string fastened to the ceiling, and a swarm of copepods, krill, and amphipods have found their final resting place in small test tubes on the nearby shelves. A warning sign with a bright red atomic symbol and Cyrillic lettering leans against the opposite wall. And next to the window with its stupendous view of mountains and ocean, there is a huge map of the High North.

Dahle has presided over the Managing Director's office for 19 of his 32 years at Akvaplan-niva. In other words, he has had plenty of time to create this wild chaos of passion, job satisfaction and adventure. From here, he has seen the workforce grow from a mere handful to today's 135 employees, presented annual accounts showing a turnover of over NOK 200 million, established close and fruitful cooperation with Russia, and ensured a high level of professional development - thus creating a company with clout.

"I usually say we started by taking on minor tasks down by the seaside, and now we've worked our way up to national and international levels. It's been an incredible journey. And I've been incredibly lucky to be along for the ride."

#### RETIREMENT CAN WAIT

Soon, Dahle will be handing over his keys. On 1 July 2019, he stepped down as Managing Director and Anton Giæver became Acting Managing Director. In March 2020, Dahle's successor, Merete Kristiansen, will arrive to take over both the helm and the office.

"To be honest, it feels quite strange not being the manager, but at the same time I must admit that it also feels great. Having 135 employees means dealing with 135 individuals. All of them are different, all of them have their issues - both in the workplace and in private. I must point out that we have an excellent system that supports good dialogue at all levels in the company. But still, when you come right down to it, I've been the person with overall responsibility. And it's rather nice not to have to worry about that part anymore."

Despite being 67 years old, Dahle doesn't plan on retiring just yet. Instead, he has taken on the position of Project Director at Akvaplan-niva. He summarises his new job description quite simply: "To do everything that is fun." In more formal terms, it means he will be in charge of developing and coordinating major projects, building networks, and training employees.

#### EAGER TO EXPLORE AT AN EARLY AGE

Salve Dahle grew up in the small village of Finland, on the outskirts of Kristiansand. His father built and maintained electricity lines, and his mother was a housewife. Young Salve was eager to explore and ready for adventure. As soon as he was old enough, he took the ferry across the strait of Skagerrak to Hirtshals in Denmark, and from there he hitchhiked around Europe. During his youth, summer holidays had two parts: he dedicated half the summer to working to earn money, and the other half to spending the money on his travels.

When Interrail was launched in 1972, Dahle was among the very first to buy a ticket. After several weeks of travelling, he eventually ended up in Israel. He became a member of a kibbutz and spent six months in this small communal settlement way out on the left wing of the political spectrum. The inhabitants worked six hours each day in return for board and lodging. Dahle's tasks involved



A radioactivity warning sign from Novaya Zemlya shares Salve Dahle's office space. The back of the sign bears the signatures of participants in the 1992 cruise to the Pechora Sea and Novaya Zemlya.  
Photo: Nordlys



everything from driving tractors and repairing machinery to picking citrus fruits, apples and cotton.

### DIVING INTO KNOWLEDGE

After returning to Norway, Dahle studied history and mathematics at the Teacher Training College in Trondheim (now part of the Norwegian University of Science and Technology), before beginning work as a teacher in Kåfjord. The reason he ended up in the north was simple: love. As early as secondary school, Dahle and his classmate Inger became friends, and a few years later they became inseparable. When Inger gained admission to medical school in Tromsø, Dahle wanted to live as close as possible. They eventually moved first to Hammerfest and later to Mosjøen.

“When we arrived in Mosjøen, we had just become parents, and while Inger was in practice, I was a stay-at-home father. In the evenings, I taught and served as head of adult education. And I started scuba diving.”

Dahle describes this as a personal turning point and says his fascination for underwater life forms made him aware of a great need for formal education on the subject. When the family moved back to Tromsø, Dahle started studying again. During the early 1980s, he graduated as a marine biologist - and eventually became the father of three children.

He spent the next few years working with computers, but ultimately realised he had a decision to make. Should he continue in the field of computers or return to marine biology?

“I concluded that marine biology was more fun. A few years previously, two of my friends, Reidulf Juliussen and Stig Falk-Petersen, had founded what was then called Akvaplan. So when I got an opportunity to work with them, the decision was a really easy one to make.”



Left: Salve Dahle, Chair, Arctic Frontiers Steering Committee at the opening of Arctic Frontiers 2020. Photo: ©Terje Mortensen / Arctic Frontiers 2020

Below: Dmitry Matishov (left) and Salve Dahle, somewhere in the Azov Sea, southwest of Russia, in August 1997. Photo: Tatiana Savinova



Gennady Matishov, Director of Murmansk Marine Biological Institute, his son Dmitry Matishov (with the rifle) and Salve Dahle at the nuclear testing site on Novaya Zemlya in July 1992. Photo: Lars Henrik Larsen / Akvaplan-niva



July 1992, Expedition to the Pechora Sea, July 1992.

Photo: Lars Henrik Larsen / Akvaplan-niva

Dahle visiting a settlement on Kolgujev Island, July 1992.

Photo: Lars Henrik Larsen / Akvaplan-niva

## MACK BEER AND SEAGULL EGGS

Dahle describes those startup years as exciting, eventful, and full of wacky antics. For a period of time, Akvaplan had an office on the top floor of a building on the site where Nerstranda shopping centre now stands, just across the square from Tromsø's legendary pub "Skarven". During one visit at the pub they wrangled permission to install a kind of pulley system between their office and Skarven. They constructed a polystyrene box in the shape of a salmon, where there was just enough room for four pints of beer and four seagull eggs.

"When we sent the salmon out the window, gravity took it all the way down to Skarven. The bartender loaded our regular order into the box, and we hauled up the goodies with a fishing reel."

*Was that a regular Friday ritual?*

"Not at all! We sent that fish out the window whenever we felt the need. It didn't have to be a Friday," says Dahle with a broad smile.

When Dahle became part of the gang at Akvaplan, Reidulf Juliussen was the Managing Director. At about this time, the company was bought up by the Norwegian Institute for Water Research (NIVA) in several stages, and renamed Akvaplan-niva AS.

In 2001, Dahle became the Managing Director.

"At that point, the company was in a very difficult situation, and two years later, in 2003, we ended up with a deficit of NOK 1.7 million. For me, that was a defining experience. I had to make people redundant, and we initiated a thorough strategic process to find a way to change our course."

## TURNAROUND

When Dahle is asked what he is most proud of during his career, it is precisely this turnaround he highlights.

"In our strategy process we decided to focus on research and building high level competence, and at the same time to use that competence to develop products and services for the public and private market. As part of this strategy, we participated eagerly in the development of the ARCTOS research network together with colleagues from the University of Tromsø, the Norwegian Polar Institute and the University Centre in Svalbard. The idea, initiated by Paul Wassmann and Stig Falk-Petersen, was that we should have enough collective professional standing to develop and raise funding for large and long-term research projects. To kick-start this, I went to Statoil, which at that point was in the process of initiating several major undertakings in the north, and I told them there were a lot of important things they needed to know that they were unaware of. And I said we could help them gain that knowledge.

"It certainly wasn't a given that we were going to succeed," says Dahle.

"In the worst-case scenario, the Akvaplan saga could have ended here. Because if we don't earn more money than we spend, we don't survive. It's that simple."

*And what was the bottom line the following year?*

"We were out of the red. Just barely. But it was enough for us to continue. And since then, we have fortunately been able to avoid that situation."



Salmon fishing on Kola Peninsula in June 2011.  
Photo: Geir Dahl-Hansen / Akvaplan-niva

## THE ARCTIC FRONTIERS BRAINWAVE

Once Akvaplan-niva was on solid financial footing, Dahle had the means and the opportunity to be innovative. What about an arena where research, trade and industry, management and other stakeholders could meet to focus on questions related to the High North? These thoughts were discussed with colleagues at ARCTOS. But where could they find financing for such an event? The work to obtain funding began in 2005. Gradually, entities such as the Research Council of Norway, ConocoPhillips, and Troms County agreed to support the initiative, and the first Arctic Frontiers conference was organised in 2007. The conference is held in Tromsø every January. In 2019, there were around 2500 registered participants.

“The goal was that Arctic Frontiers would become the most important international conference in the world for discussions related to the development of industry, society, and research in the Arctic. And now we’ve achieved it,” says Dahle. “One important element that we have always had

in mind is that the conference should not simply promote Tromsø. The conference is held here, but our objective isn’t to promote our own people. It’s about creating a national team, including strong international participation, as well as solid participation of youth and young researchers.”

*Ongoing global warming and the decline of Arctic sea ice have drawn increasing attention during Arctic Frontiers. What does this mean for people and industry in the High North?*

“When you discuss climate change and emissions of CO<sub>2</sub> due to use of fossil fuels, you must put this in context - a global context. Access to energy has been a crucial factor for lifting hundreds of millions of people out of poverty during recent decades,” says Dahle.



Elena Kudryashova, rector of the Northern Arctic Federal University (Arkhangelsk), and Salve Dahle receiving the Lomonosov Reward in November 2011.

*Photographer unknown*

*Photo: Ingun A Mæhlum*

“There are currently seven billion people on Earth, and the population is increasing by about 70 million each year. Human beings are consuming more and more of the earth’s resources and the habitats of all other species are constantly shrinking and being degraded. The latest UN biodiversity report highlights loss of habitat as the biggest threat. Providing food, clean water and clean air to a growing population, while at the same time protecting the environment and other species’ habitats - that will be one of the world’s greatest challenges in the years to come.”

#### **KEEPING HISTORY ALIVE**

Both as the Managing Director at Akvaplan-niva and in connection with the development of Arctic Frontiers, Dahle’s focus has been on innovation,

development and the future. However, his love of the north has just as much focus on the past. He was Chairman of the Arctic Society in Tromsø for eleven years and oversaw many projects, including the erection of a monument in memory of the polar explorer Helmer Hanssen.

“Tromsø as part of coastal Norway has an important history that must be cherished. This entire community is founded on what was achieved and created by those who came before us. Growing up in Norway and living here at the gateway to the Arctic Ocean has helped to stimulate my interest in history.”

It’s all about the constant pursuit of the unknown, of adventure.

“Is there anything more exciting than that?” asks Salve Dahle, before quickly answering his own question:

“No!” ■

Rolf A Ims, John-André Henden and Marita Anti Strømeng // UiT The Arctic University of Norway  
Jane Uhd Jepsen // Norwegian Institute for Nature Research

# The Arctic is greening, bird populations are declining: Is there a link?

## RESEARCH NOTES

Ecological theory predicts that increased productivity at the base of food chains may raise predation rates at intermediate levels. New research by the Climate-ecological Observatory for Arctic Tundra (COAT) finds a link between plant productivity in tundra landscapes and bird nest predation rates.

**T**HE ARCTIC IS HOME TO ABOUT 200 SPECIES and tens of millions of individual birds. Most of them migrate north every spring to nest on the Arctic tundra. After two or three hectic months, they return to their wintering grounds much further south. Biologists have wondered why so many birds embark on these long and potentially dangerous journeys to the top of the world to breed. One leading hypothesis is that the Arctic offers a lower predation risk than more southern regions, and thus a safer place for raising offspring.

### INCREASED NEST PREDATION

Eggs and chicks are extremely vulnerable to predation, especially in species that place their nest on the ground. Arctic ecosystems usually have few predators and nest predation rates have historically been lower here than in boreal and temperate ecosystems. However, this now appears to have changed. A global-scale meta-analysis published in *Science* two years ago showed that nest predation

rates in shorebirds - a group of species of which many are endemic to the Arctic - have increased globally since the 1990s, but most profoundly in tundra ecosystems. This result corresponds well with reports of declining population trends in many of the same species. The *Science* paper speculated that changes induced in Arctic vegetation or in the rodent population cycle by climate warming could enhance nest predation.

### ARCTIC GREENING

Last year a team of COAT researchers published a study in *Nature Climate Change* that provided evidence for a link between increased nest predation and changed vegetation through a phenomenon termed *Arctic greening*. Arctic greening is due to increased plant biomass (ecosystem primary productivity) that results from longer and warmer growing seasons. The level of greenness is usually quantified by remote sensing (satellite data), and several remote sensing studies have shown that the Arctic tundra has become greener, concur-



Photo: Geir Vie

rent with climate warming. However, the level of greening is typically unevenly distributed in space, presumably due to other factors limiting plant growth, such as herbivory and site fertility.

#### **NEST PREDATION EXPERIMENT**

The COAT study included nine mountainous tundra landscapes with varying levels of greenness distributed across Finnmark (70-71°N) in northern Norway. During five consecutive summers, 900 experimental bird nests were distributed among these tundra landscapes. Overall, predation rates increased by 72% from the least green to the greenest landscape. This result accords well with ecological theory that predicts food webs subjected to increased primary productivity can sustain more omnivores and generalist predators like corvid birds and foxes. The design of the study also included elevation gradients from the alpine treeline to the mid-alpine zone in each of the mountainous landscape areas. Predation rates increased with increasing elevation, suggesting

that bird species nesting at high altitudes may be particularly impacted by predation.

#### **RODENT POPULATION CYCLE**

The study encompassed all phases of the four-year rodent population cycle that typifies tundra ecosystems. Nest predation rates peaked one year after the peak phase of the rodent cycle. This finding was in accordance with the expected numerical and functional response of predators based on previous studies. Typically, predators feast on rodents and produce many offspring during the rodent peak (numerical response). When the rodent population crashes in the next phase of the cycle, the now abundant predators must shift to alternative prey such as bird eggs (functional response). Unexpectedly, however, the predation rate continued to be quite high for 2-3 years after the rodent peak. Such an extended delayed overall response of the predators relative to the rodent cycle acts to increase the cumulative impact of predation.

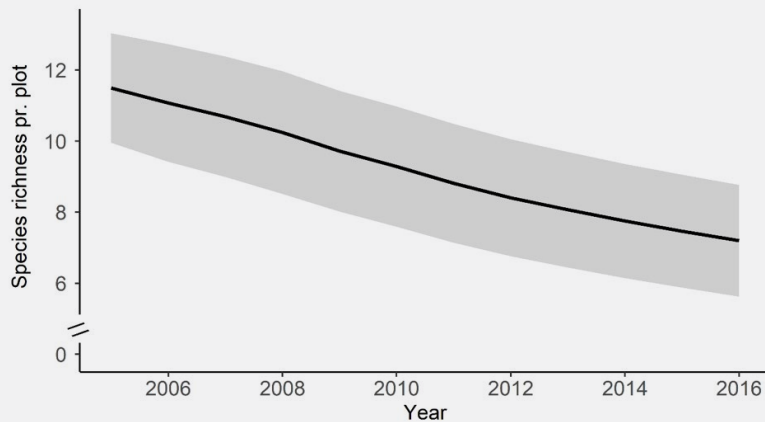


Four bird species nesting on tundra that have recently been placed on the Norwegian red list. Bluethroat (top left), Lapland longspur (top right), willow ptarmigan (bottom left) and a female long-tailed duck with chicks (bottom right). All photos were taken on the Varanger Peninsula. *Photos: Geir Vie*



Experimental methods for studying nest predation. Top left: One of the experimental nests in the COAT study consisting of one quail egg and one plasticine egg. Top right: A natural shorebird nest (golden plover). Bottom left: A plasticine egg with the beak mark of a nest predator (most likely a raven). Bottom right: A raven robbing one experimental nest as revealed by a motion-sensitive trail camera. *Photos: COAT*





Estimated trend in local species richness (number of species per census plot) of tundra birds during a decade in COAT's monitoring plots on the Varanger peninsula.

### WHICH PREDATORS?

It is important to know the identity of the predator species involved, both to understand the basis for the delay in the predator response to the rodent cycle and to assess whether management actions could reduce predation rates. An attempt was therefore made in the COAT study to identify which predators robbed the nests. This was done by placing one egg made of plasticine in the experimental nests. Marks left on the plasticine eggs indicated that corvids (ravens or crows) were responsible for most of the predation in the COAT study. However, this method was also found to be rather imprecise, both because it was difficult to differentiate between marks left by different predator species and because many of the eggs were removed by predators. Hence, there is a great need to develop better methods. Using motion-sensitive trail cameras at nest sites is one possibility. Because corvids learn rapidly, a problem with such cameras is that they may attract ravens as soon as they learn that cameras are associated with a good meal.

### RED-LISTED TUNDRA BIRDS

Several bird species nesting in the tundra have recently been placed on the Norwegian red list. Within COAT's monitoring plots on the Varanger Peninsula, the species richness of tundra birds has

declined by approximately 30% over a single decade. The red-listed bird species constitute a mixed group in terms of trophic position in the food web (both insectivores like the Lapland longspur, and herbivores like the willow ptarmigan), habitat (both land birds and freshwater ducks) and degree of residency (both long-distance migrants like bluethroats, and year-round residents like ptarmigans). What they have in common, however, is that they all place their nests on the ground and are thus likely to be impacted by an increasing number of nest predators in a warming Arctic. ■

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### FURTHER READING:

Kubelka T, Šálek M, Tomkovich P, Végvári Z, Freckleton RP, Székely T (2018) Global pattern of nest predation is disrupted by climate change in shorebirds. *Science* <https://science.sciencemag.org/content/362/6415/680>

Ims RA, Henden JA, Thingnes AV, Garmo MJ, Strømeng MA, Jepsen JU (2019) Greening Arctic and bird nest predation risk across tundra ecotones. *Nature Climate Change* 9 <https://doi.org/10.1038/s41558-019-0514-9>

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Haakon Hop, Agneta Fransson and Allison Bailey // Norwegian Polar Institute

Melissa Chierici, Solfrid Sætre Hjøllo and Sam SP Rastrick // Institute of Marine Research

Philip Wallhead and Marianne Karlsson // Norwegian Institute for Water Research, Bergen

Howard I Browman // Institute of Marine Research, Austevoll Research Station

Claudia Halsband // Akvaplan-niva

Johanna Järnegren // Norwegian Institute for Nature Research, Trondheim

# A warming, more acidic ocean – future challenges for Arctic marine organisms

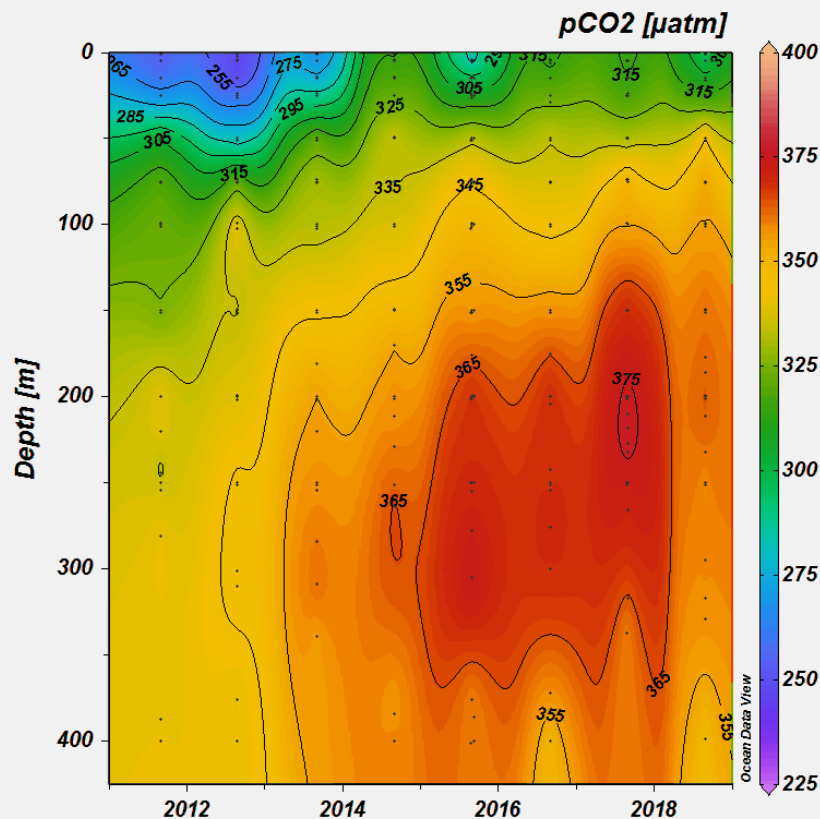
## RESEARCH NOTES

The possible impacts of ocean acidification (OA) on Arctic marine ecosystems is a primary concern, especially on time scales beyond the next election, or beyond our own lifetimes. The Fram Centre's Ocean Acidification Flagship seeks answers to this challenge.

**T**HE COLD ARCTIC OCEAN AND MARGINAL SEAS are changing, with higher sea-surface temperatures and less sea ice, but are also getting more acidic (i.e. less basic) as they absorb anthropogenic CO<sub>2</sub> from the atmosphere. The CO<sub>2</sub> absorbed raises the partial pressure of CO<sub>2</sub> ( $p\text{CO}_2$ ), increases the hydrogen ion concentration (lowering pH), and removes carbonate ions, thus lowering saturation states for calcium carbonate ( $\Omega$ ). In a short-term perspective of seasons and years, changes in oceanic pH may not be very noticeable, but in the marine environment and in experiments, the effects of OA are measurable and can potentially become severe for marine organisms that utilise calcium carbonate in their skeletal structures. Non-calcifying organisms can also be

affected by OA due to physiological responses that can influence feeding or the costs of maintaining homeostasis, which modulate energetic trade-offs controlling growth and reproduction.

The Ocean Acidification Flagship at the Fram Centre has conducted research projects on different aspects of OA during the last decade. A nine-year oceanographic time series has been established to track the OA state in Fram Strait, investigating both the Arctic outflow waters in the East Greenland Current and in the Atlantic water inflow. The time series is now starting to show decreased pH and increased  $p\text{CO}_2$  throughout the water column in the East Greenland Current (see graph next page). In addition to the Fram Strait study, we



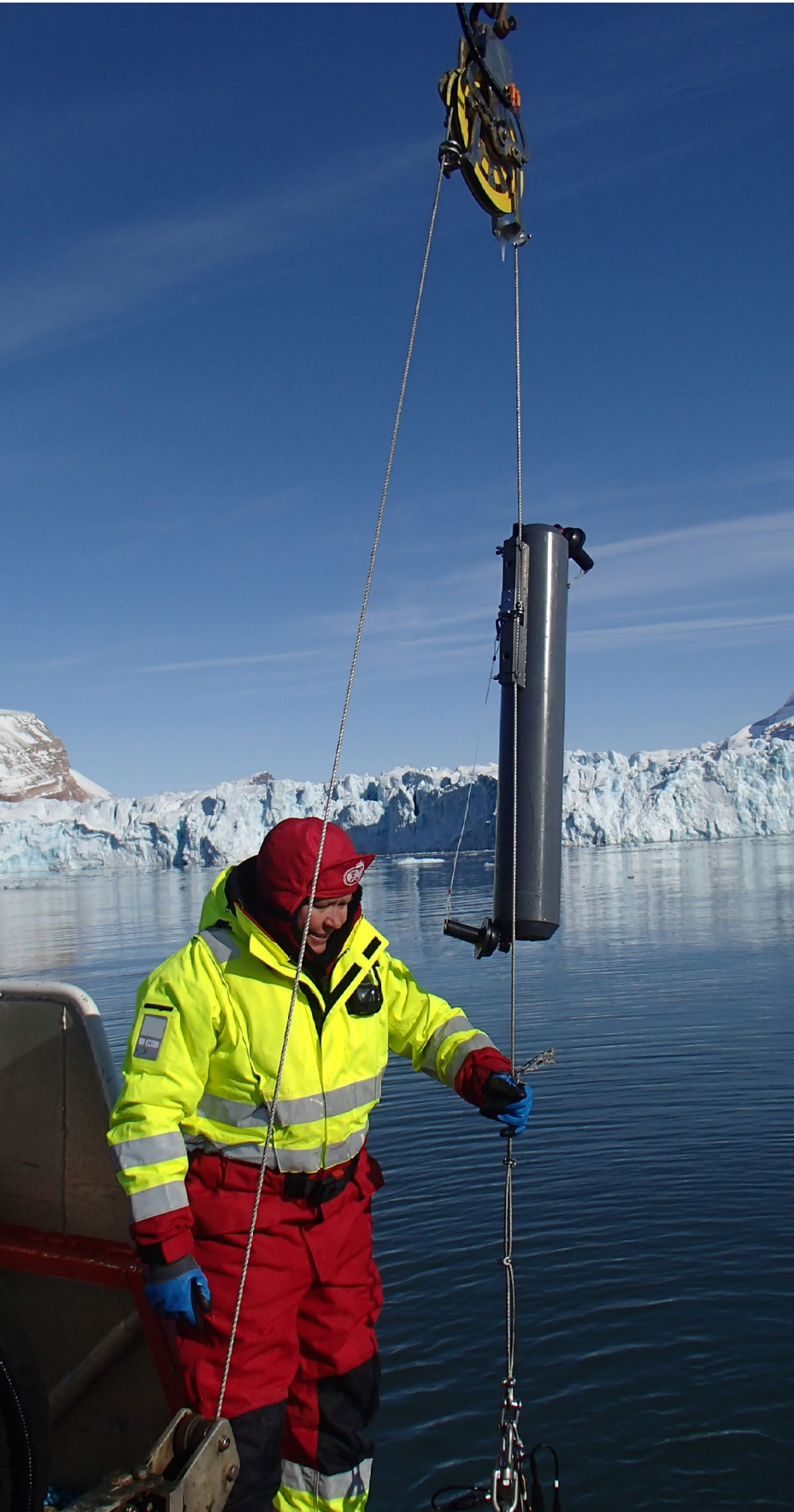
Changes in  $p\text{CO}_2$  (scale in  $\mu\text{atm}$ ) in Arctic water exiting the Arctic Ocean in the East Greenland Current from 2011-2018.  
Graph: M Chierici and A Fransson, unpublished data

investigate the effect of freshwater from glacial melt in Svalbard fjords and have found reductions in alkalinity near the glaciers, with potential consequences for calcifying organisms.

The second part of our flagship deals with biological effects. Studies on calcified skeletons and shells of marine organisms have shown that those with a high proportion of the calcite form of calcium carbonate are less affected than those with more of the aragonite form. Copepods, which have a tough exoskeleton composed of chitin, protein, and calcium carbonate, have important functions in the marine food web. If they were to be affected by OA, the consequences for the pelagic ecosystem would be severe. The

good news for both boreal and Arctic copepods (*Calanus finmarchicus* and *C. glacialis*) is that they are largely robust to OA, although some life stages and populations are more sensitive than others. Invertebrate DNA may also be vulnerable to ocean acidification-induced damage, and transcriptional changes in DNA repair mechanisms have been reported for *Calanus glacialis*. We compare the susceptibility of common Arctic copepods (*Acartia* sp. and *Calanus* sp.) to DNA damage against that of temperate taxa to estimate the impacts of future low pH on the DNA integrity of these important food-web elements.

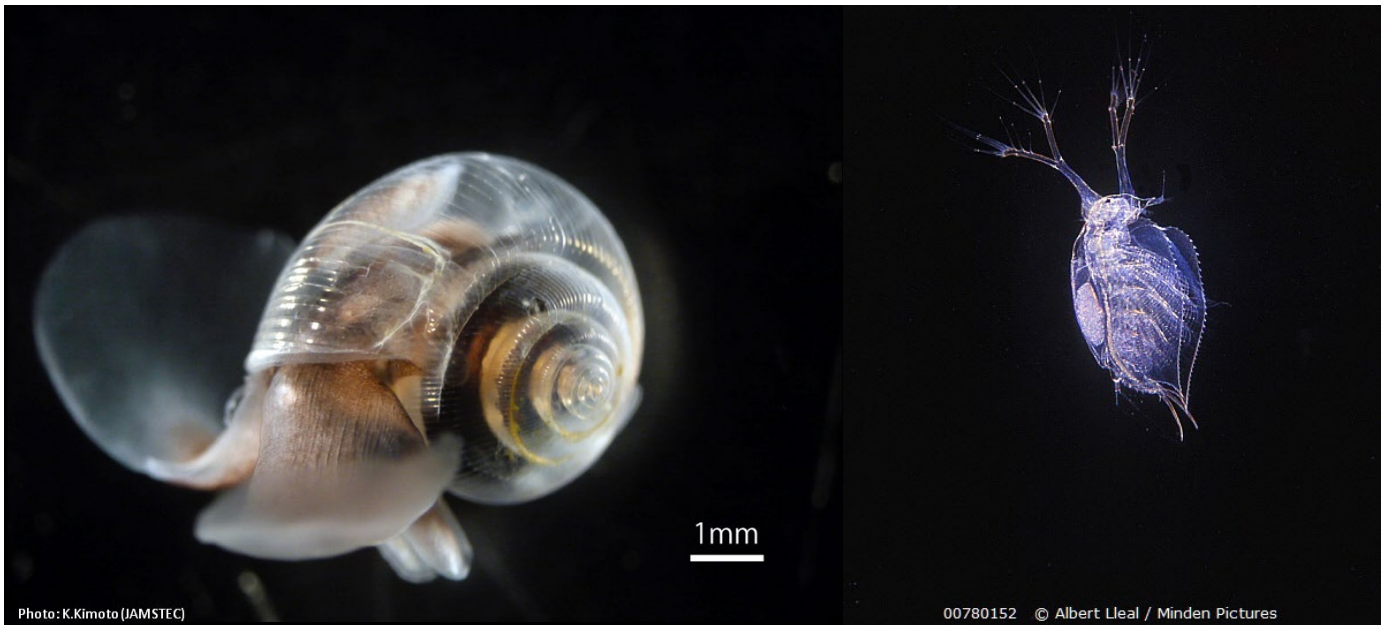
Finding good model organisms for effect studies of OA is challenging. The sea butterfly snail



Agneta Fransson collects a water sample for carbonate chemistry in Kongsfjorden, Svalbard. Photo: Helene Hodal Lødemel / Institute of Marine Research

Allison Bailey with a gammarid amphipod *Gammarus setosus*. Photo: Allison Bailey / Norwegian Polar Institute





The pteropod sea butterfly *Limacina helicina*, with delicate shell of aragonite.  
Photo: Katsunori Kimoto / JAMSTEC

The cladoceran *Penilia avirostris* (size 1 mm).  
Photo: Albert Lleal / Minden Pictures

*Limacina helicina* has been sampled along chemical and physical gradients and used as a proxy for climate-change effects on its shell condition. Pilot experiments have been done with cladocerans (small crustaceans), whose clonal reproduction allows for investigations into how specific genotypes respond to OA. They have fast life cycles (i.e. weeks), which makes it possible to study them over several generations. Thus, a multigeneration study on the combined effects of temperature and CO<sub>2</sub> on gene expression and epigenetic response in *Penilia avirostris* is currently being performed in order to assess whether it can keep up with the rate of change cause by OA. Ocean acidification has the potential to affect sexual reproduction and early life-history stages. The cold-water coral *Lophelia pertusa* has a long life cycle where embryonic development slows down at higher pCO<sub>2</sub> levels, while increased temperature speeds it up.

Long-term monitoring of organisms in field situations to determine the effects of OA has started, but another approach is to use natural analogues to investigate effects of both climate change and ocean acidification. Spatial differences in environmental conditions (temperature, salinity, pCO<sub>2</sub>) can be used as an analogue for environmental changes over time. A recent study in Kongsfjorden, Svalbard, sampled shallow-water amphipods (*Gammarus setosus*) along salinity gradients to determine how different populations respond to salinity as well as elevated pCO<sub>2</sub>. In this case, populations inhabiting low-salinity waters near the glacier front appear to have gained tolerance to the challenge of low salinity, indicating that they may be able to respond similarly to future freshening associated with climate change. The project showed that their physiology responded more to salinity than to elevated pCO<sub>2</sub>, both of which influence pH.



The amphipod *Gammarus setosus*, found in high numbers amongst the rocks of the intertidal zone in Kongsfjorden, provides food for higher trophic levels such as seabirds. Flagship researchers studied the effect of OA on the energy use and homeostasis of the species at several sites in Kongsfjorden and Krossfjorden in the summer of 2018. Metabolic rate was measured as oxygen uptake for individual *G. setosus* in closed chambers filled with ambient sea water from their sampling site.

Photo: Allison Bailey / Norwegian Polar Institute

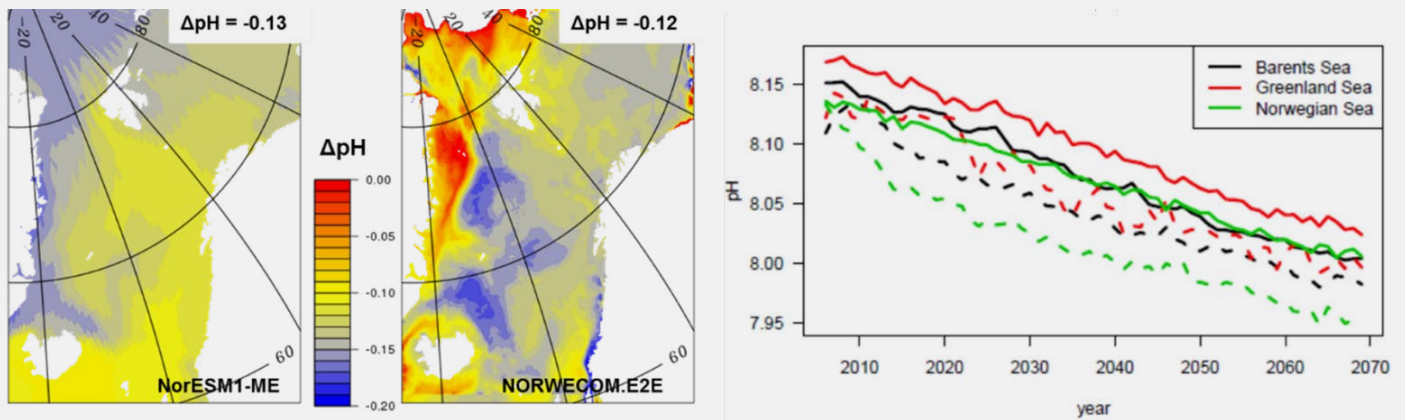


To study the future acidification, as changes in pH, of northern waters and its impacts on marine ecosystems in combination with other stressors, we are using a multi-model approach. These models are forced by IPCC atmospheric CO<sub>2</sub> scenarios to determine basin-wide, regional and local (site-specific) scenarios of biogeochemical and ecosystem change. Recent models have obtained better representations of sea ice, organic carbon, and primary production, as well as improved horizontal resolution. Modelling has also been used to project ecosystem response and feedback to OA, such as potential changes in benthic habitats and communities. How real-world marine food webs absorb change, recover, and adapt (i.e. ecological resilience) to climate change remains a big question. In a modelling project involving long-term data (2004-2016) from Kongsfjorden, we found that the core ecological processes were maintained despite significant environmental perturbations, including ocean acidification. The study showed that Arctic marine food webs can absorb and begin to adapt to ongoing climate change.

The social science component of the Flagship's work seeks to determine how scientists and environmental managers view, handle, and communicate uncertainties related to OA. We found that scientists have a clear understanding of uncertainty as an integral part of conducting, analysing, and communicating their research. Environmental managers handle scientific knowledge in the context of multiple stressors and broader ocean management and therefore need ocean acidification knowledge tailored to their reality. The study shows that the differences between scientists and managers should be acknowledged to improve research communication and potential management strategies. ■

Weight-specific oxygen consumption rates for *Gammarus setosus* can be calculated from the drop in oxygen saturation over time in amphipod respiration chambers. James Brown and Alison Bailey are setting up the experiment on the beach in front of the Marine Laboratory in Ny-Ålesund, with supervision and cheering from Sam Rastrick.

Photo: Wojtek Moskal / Norwegian Polar Institute



Annual mean change in pH (last decade – first decade of simulation) for the NorESM1-ME (left panel) and NORWECOM (middle panel) model. Right panel: Annual mean (0–10 m) pH for Barents Sea (black), the Greenland Sea (red), and the Norwegian Sea (green), for NorESM1-ME (solid line) and NORWECOM (dashed line) (Reproduced with permission from Skogen et al (2018) ICES Journal of Marine Science 75: 2355-2369. <https://doi.org/10.1093/icesjms/fsy088>)

## INSTITUTIONS AND PARTICIPANTS IN THE OCEAN ACIDIFICATION FLAGSHIP

### Institute of Marine Research (IMR)

Melissa Chierici (Lead), Samuel SP Rastrick, Solfrid Hjøllø, Howard I Browman, Cecilie Hansen, Elizabeth Jones, Helene Hodal Lødemel, Erik Mousing, Morten Skogen

### Norwegian Polar Institute (NPI)

Haakon Hop (Co-lead), Agneta Fransson, Allison Bailey, Ylva Ericson, Mats A Granskog, Gary P Griffith

**Norwegian Institute for Water Research (NIVA)** Philip Wallhead, Richard GL Bellerby, Marit Nordli, Kai Sørensen, Andrew L King, Trond Kristiansen, Elizaveta Protsenko, Andre Staalstrøm, Evgeniy Yakushev

**Norwegian Institute for Nature Research (NINA)** Johanna Järnegren

**Akvaplan-niva** Claudia Halsband

**NORCE** Anne-Katrine Norrman

**SALT** Jannike Falk-Andersen

### UiT The Arctic University of Norway

Trine Rasmussen, Kasia Zamelczyk

### University Centre in Svalbard (UNIS)

Eva Falck, Ane Cecile Kvernvik

**Scottish Association for Marine Science (SAMS)** Helena Reinardy

**Grótti ehf** Steven Shema

**Bangor University, UK** Nia M Whiteley

**University of Chester, UK** James Brown

**JAMSTEC, Japan** Naomi Harada, Katsunori Kimoto

**University of Gothenburg, Strömstad, Sweden** Pierre De Wit

**Institute of Oceanology, Sopot, Poland** Piotr Kuklinski

**Bigelow Laboratory for Ocean Sciences, Maine, USA** David M Fields

**IMEDEA, Spain** Iris E Hendriks

**Woods Hole Oceanographic Institute, USA** Neel Aluru

**Arizona State University, USA** Michael Bernstein

**Université du Québec à Rimouski, Quebec, Canada** Piero Calosi

**Alfred Wegener Institute, Bremerhaven, Germany** Clara JM Hoppe

**Gulf of Maine Research Institute, University of Maine, USA** Jeffrey Runge

**Florida State University Coastal and Marine Lab, USA** Sandra Brooke

Justin P Gwynn // Norwegian Radiation and Nuclear Safety Authority

Hilde Elise Heldal // Institute of Marine Research

# Expedition to the sunken nuclear submarine *Komsomolets* in the Norwegian Sea

## RESEARCH NOTES

On 7 April 1989, the Soviet nuclear attack submarine *Komsomolets* sank in the Norwegian Sea after a fire broke out. In the summer of 2019, Norwegian scientists finally had a chance to see the wreck on the seafloor with their own eyes and assess the status of any radioactive releases from the submarine.

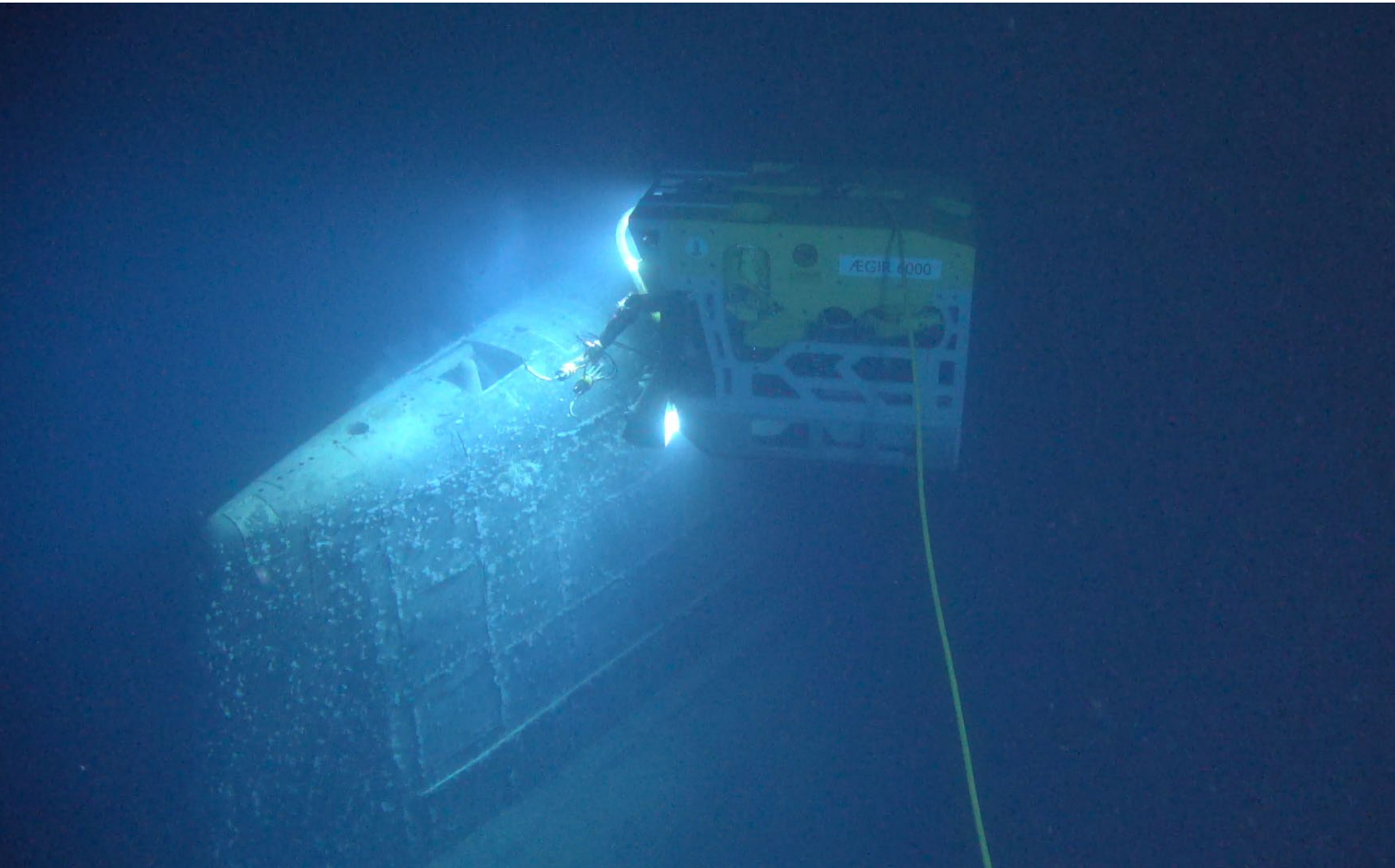
**T**HE 2019 EXPEDITION TO *KOMSOMOLETS* was organised under the Norwegian-Russian expert group for investigation of Radioactive Contamination in the Northern Areas, with participants from the Institute of Marine Research, the Norwegian Radiation and Nuclear Safety Authority, the Norwegian University of Life Sciences, and a Russian observer from the Research and Production Association “Typhoon”. The expedition took place on the RV *G.O. Sars* and used the remotely operated vehicle (ROV) *Ægir 6000* to collect samples in order to detail the levels of radioactivity in the environment. Such information is important to understand any potential risks associated with

*Komsomolets* and to ensure consumer confidence in Norwegian seafood.

Following the sinking of *Komsomolets*, a number of Soviet and Russian expeditions were carried out between 1989 and 2007 using manned submersibles. Initial investigations showed that the front part of the submarine had suffered considerable damage, with holes and cracks in both the outer hull and the inner pressure hull. In 1994, the six torpedo tubes along with some holes in the torpedo section were covered to reduce the flow of seawater into the torpedo compartment. Releases of radionuclides from the reactor in *Komsomolets*

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*Ægir 6000 ROV taking samples near the tower of the sunken nuclear submarine Komsomolets. Photo: Institute of Marine Research and University of Bergen/Ægir 6000*

have been detected in a ventilation pipe that forms a connection between the compartment next to the reactor and the open sea.

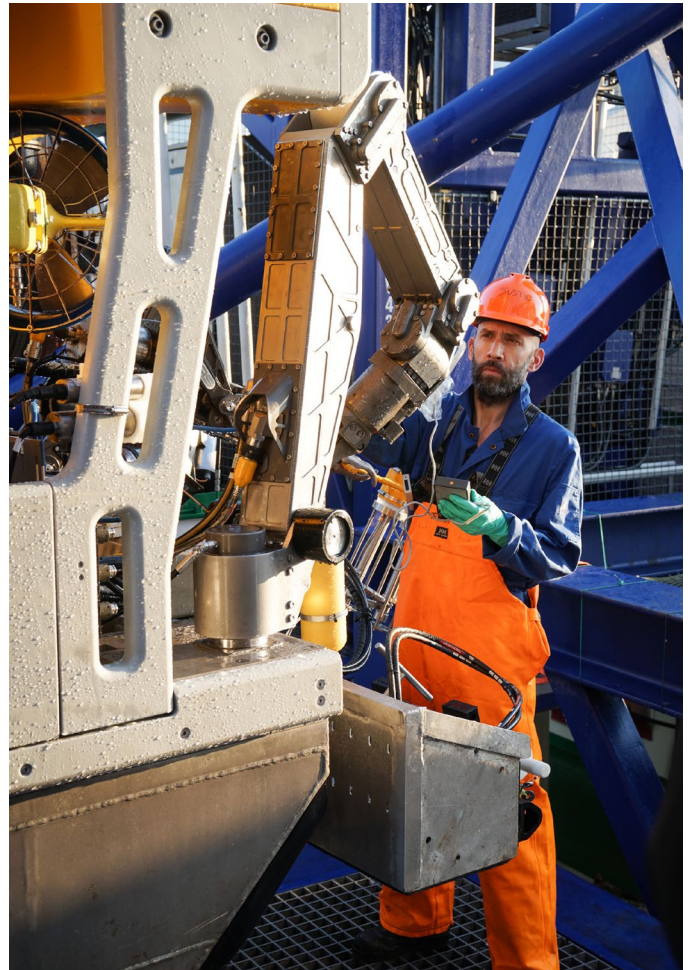
Norway has monitored the marine environment around *Komsomolets* annually since 1990 and releases from the reactor were detected in surface sediments and bottom water around the submarine in the early 1990s. However, since then and up to 2018, all samples collected around *Komsomolets* have shown radionuclide levels typical for the Norwegian Sea. However, these samples were collected using traditional equipment.

- *Komsomolets* (K-278) sank in the Norwegian Sea on 7 April 1989.
- The submarine lies at a depth of 1680 m, southwest of Bjørnøya.
- *Komsomolets*' nuclear power source was a single pressurised water reactor.
- *Komsomolets* carried two nuclear plutonium warheads in its armament when it sank.
- Of the 69 crew members, 42 were killed as a result of the accident and eventual sinking.



The Ægir 6000 ROV being set out from the RV G.O. Sars to begin its descent to the seafloor. Photo: Institute of Marine Research

The Ægir 6000 ROV was checked for any possible contamination each time it was brought back onboard the RV G.O. Sars. Photo: Institute of Marine Research



Sediment cores collected around the hull of *Komsomolets* were carefully handled onboard for later analysis. Photo: Institute of Marine Research





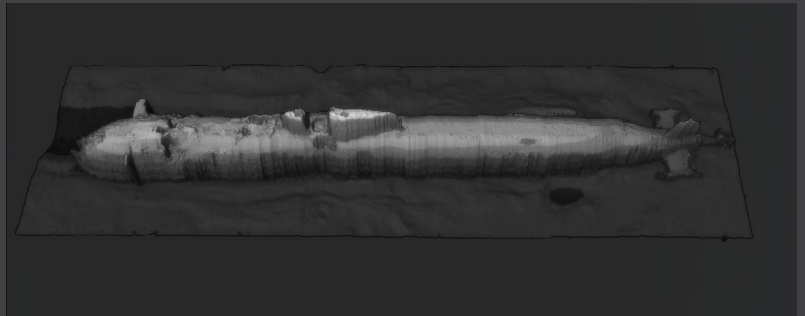
Expedition leader Hilde Elise Heldal (Institute of Marine Research) and scientific leader Justin Gwynn (Norwegian Radiation and Nuclear Safety Authority) in the ROV control room onboard the RV *G.O. Sars*.  
Photo: Institute of Marine Research

In 2019, the *Ægir 6000* ROV gave Norwegian scientists their first opportunity to take water samples directly from the ventilation pipe where releases had been detected earlier, to take sediment samples within one metre of the submarine, and to sample biota growing on the hull. Video of *Komsomolets* on the seafloor clearly shows the damage to the outer and inner hulls in the forward section of the submarine. The coverings over the torpedo tubes and the torpedo compartment installed by Russia in 1994 were still in place. Water samples collected from the ventilation pipe on the first dive with the ROV revealed no sign of any releases. On subsequent dives, however, a cloud could be seen coming out of the ventilation pipe. Water samples collected from the ventilation pipe when the cloud was visible showed levels of Cesium-137 between 30 and 792 Bq/l, with lower levels in samples collected within the cloud approximately 40 cm above the ventilation pipe. Although

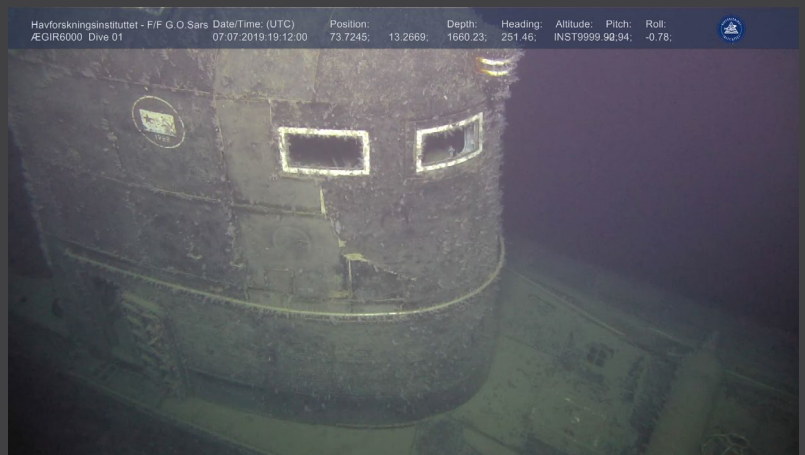
the maximum observed level of Cesium-137 was approximately 800 000 times higher than typical for the Norwegian Sea (0.001 Bq/l), such releases are not expected to have any consequences for the marine environment due to the depth at which *Komsomolets* lies and the dilution of any releases. It can be assumed that releases from the reactor have been occurring since *Komsomolets* sank in 1989, but no unexpectedly high levels of radionuclides in sediments, seawater or marine organisms have been observed in the Norwegian Sea during this time.

All water, sediment and biota samples will now be analysed in greater detail to allow us to better understand the releases from the reactor and whether there have been any releases of plutonium from the warheads in the torpedo compartment. We expect a final report to be published in 2020. ■

High resolution multibeam sonar image of the sunken nuclear submarine *Komsomolets* on the seafloor.



The sunken nuclear submarine *Komsomolets* at the bottom of the Norwegian Sea.

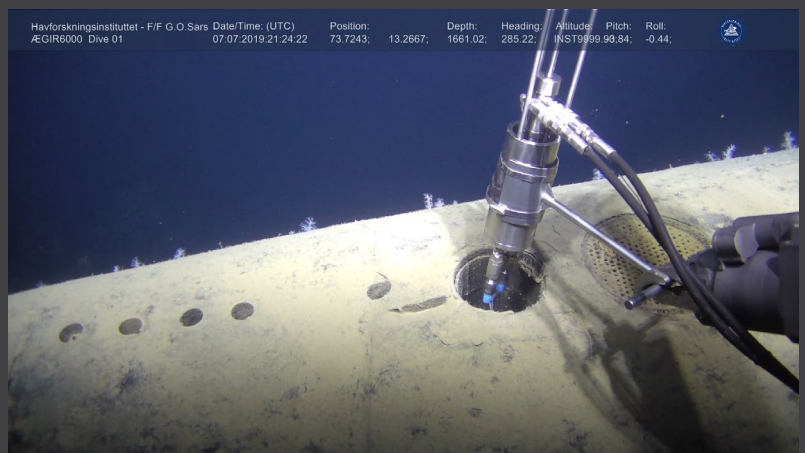


When a “cloud” was seen coming from the ventilation pipe (to the right), Cesium-137 from the reactor in *Komsomolets* could be detected in collected seawater.



Water samples were collected directly from the ventilation pipe where releases had been detected earlier using syringe samplers operated by the Ægir 6000 ROV.

All images: Institute of Marine Research and University of Bergen/Ægir 6000



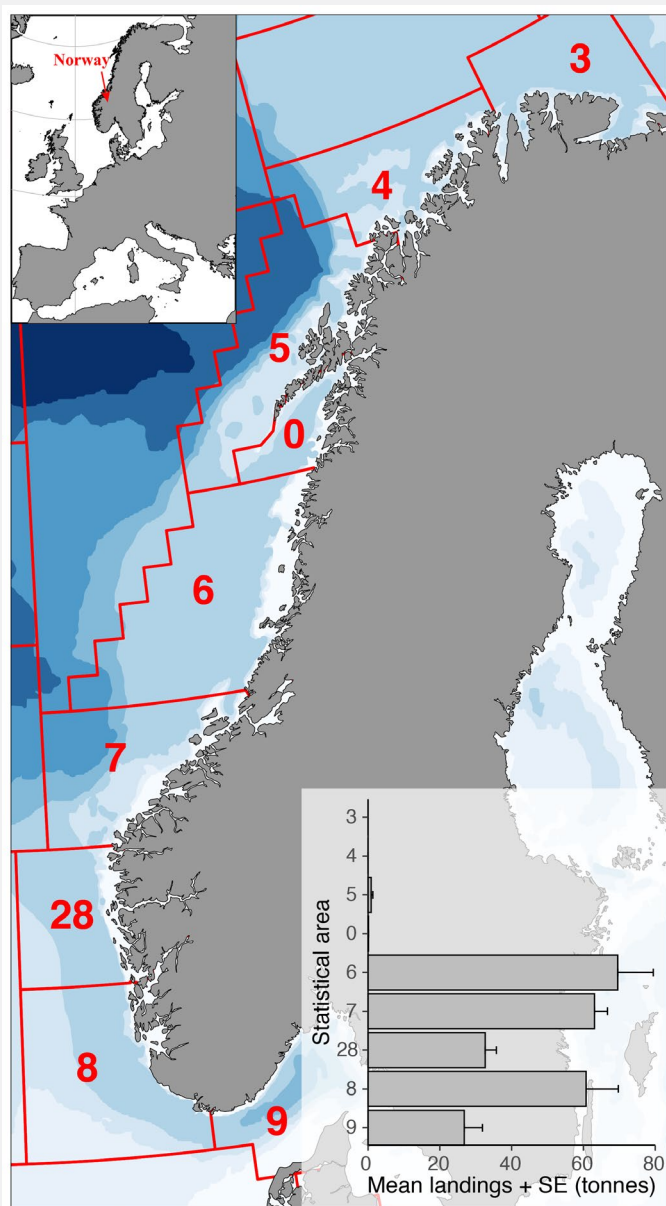


Claudia Junge, Ole Thomas Albert and Marlén K Myrlund // Institute of Marine Research  
Maja K Rodriguez Brix // The Norwegian Directorate of Fisheries

# A feisty shark in Norwegian waters – the tale of the spurdog

## RESEARCH NOTES

Marine predators are key species in many ecosystems and can function as indicators of food web health. The spurdog (*Squalus acanthias*) is a small coastal shark that can be found in temperate and boreal waters around the world. This shark, also known as spiny dogfish, has an interesting tale to tell.



Norwegian statistical areas covering the coast between 58 and 71°N. Mean annual landings per area (in tonnes) for the years 2014–2018.

From Albert et al, *Young mums are rebuilding the spurdog stock (Squalus acanthias L.) in Norwegian waters*, *ICES Journal of Marine Science*, fsz156. doi:10.1093/icesjms/fsz156, reproduced with permission from Oxford University Press.

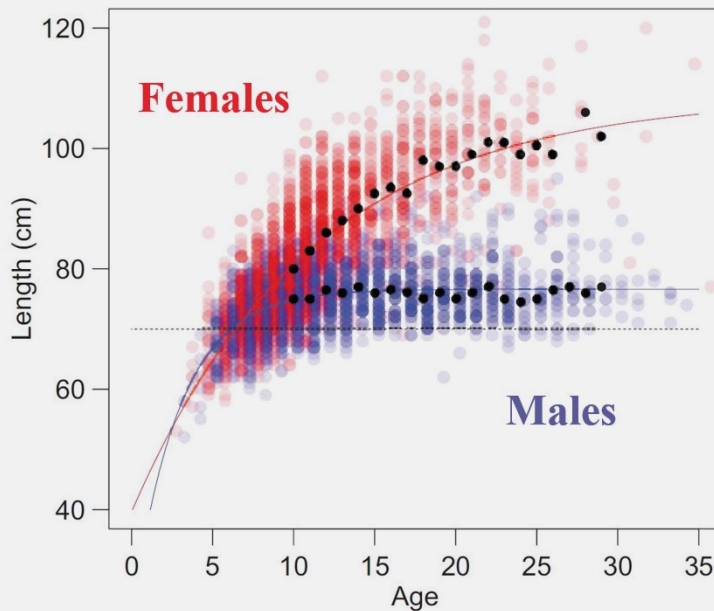
**S**PURDOGS FORM LARGE SCHOOLS, which means that they can be caught in large quantities, once encountered by fisheries. Males and females often form their own schools, as do large and small fish. Females give birth to a small number of live offspring after two years of pregnancy, one of the longest gestation periods known among vertebrate species. Therefore, capturing large schools of pregnant females has a significant effect on future recruitment levels. For these reasons, spurdog, like many other shark species, is considered particularly vulnerable to overexploitation.

### SPURDOG FISHERY – PAST AND PRESENT

The northeast Atlantic spurdog fishing stock has undoubtedly been very large and has provided a basis for valuable fishing for over a hundred years. It has long been sought after for its liver oil and meat. After several decades of overfishing, with annual landings peaking in the 1950s/60s at 30 000–60 000 tonnes, the stock size reached a historic low in the early 2000s. At that time, the stock biomass was only about 20% of the previous level. After that, stricter management measures were introduced, and the stock has since been increasing. Major fishing nations were France, the United Kingdom, and Norway.

There is currently no targeted fishery on this stock, and according to the latest assessment by the International Council for the Exploration of the Sea (ICES), the stock has not been overfished since 2005. The population now seems to be on the path to recovery, though according to the current assessment model it will probably be more than 20 years before spurdog numbers reach the desired level. However, data on important life history parameters used in the assessment of this stock, such as growth, fecundity, as well as the population's sex and age composition, originate mainly from the period before the stock collapsed. The paucity of recent knowledge on those critical life history parameters for the entire population and the complete lack of such data for Norwegian waters was the motivation for our comprehensive study investigating 3 948 individual spurdogs from along the Norwegian coast.





Length at age for spurdog after correcting for spine wear. Black dots indicate median length at age for age 10–30 years. Coloured lines represent von Bertalanffy growth models for each sex, and the dashed line indicates minimum landing size. From Albert et al, *Young mums are rebuilding the spurdog stock (Squalus acanthias L.) in Norwegian waters*, *ICES Journal of Marine Science*, fsz156. doi:10.1093/icesjms/fsz156, reproduced with permission from Oxford University Press.

#### DID YOU KNOW?

##### Spurdog

- females can grow up to 122 cm, and males up to 95 cm
- is long-lived and has been found up to 75 years of age
- is slow-growing and matures around the age of 15 years
- females give birth to 7-11 live offspring
- is distributed mainly at depths of 10–200 m
- in the northeast Atlantic can be found from Iceland and the Barents Sea southward to the northwest coast of Africa

#### SHARKS CAN BE AGED

- based on incrementally grown structures like spines, vertebrae, thorns, and eye lenses
- using spines. The challenge with using an external feature like the spines, is wear and breakage. To account for the number of growth bands missing due to wear, a correction method should be applied.
- using vertebrae, by counting the growth rings formed on them (but be careful with bias!)
- via “bomb radiocarbon” which involves testing carbon radioisotopes in shark growth bands. These isotopes act as a “time stamp” for any shark that was alive when nuclear bomb testing of the 1950s and 1960s littered our atmosphere with traces of radiocarbon. This method can therefore be applied to old individuals (currently >70 years) and some old samples e.g. those in natural history collections.



Processing of spurdog at our facility in Tromsø. Thanks to all the processing teams!

Photos: Institute of Marine Research

Spurdog is currently landed in Norway mainly at landing sites in the southern half of the west coast. While spurdog is landed in every month of the year, there are two main landing periods: one in spring (April-May) and one in winter (September-January). According to fisher organisations, the prevalence of spurdog seems on the rise, and more catches have been reported from different areas of the country. Since 2011 the annual Norwegian landings have been stable at 216-313 tonnes, which is significantly more than other countries.

#### IMPORTANT LIFE HISTORY PARAMETERS

We analysed whole specimens collected from landing sites along the Norwegian coast between 2014 and 2018; most had been caught by gillnet (87%). We dissected the specimen, collecting a large amount of data and samples. We measured the spurdog's total length and weight and determined its sex and sexual maturity stage. In

addition, we measured sexual characteristics of female and male reproductive organs, and collected samples such as spines, stomachs, vertebrae and tissue. This is a somewhat messy job, but it provides a lot of important data, ensuring optimal use of captured spurdog individuals, to yield the greatest possible knowledge gain.

Spurdogs - a.k.a. spiny dogfish - have spines in front of their two dorsal fins (on their back), which is great, as we can use those to figure out how old an individual shark is. We counted the number of growth bands on the second dorsal spine, similar to the way tree rings are counted, to determine the age of each sampled spurdog. Using spines for ageing was shown to be more reliable than using the shark's vertebrae. The annual deposition of growth bands in the enamel of the spine has been validated before, confirming a correlation between the number of rings and the age of the shark. However, recent research shows that the

older a shark is, the less its growth bands might correspond to its age, which means that this type of ageing data might tend to underestimate especially the older ages.

In our study, we found males and females ranging in age from 3 years to their mid-30s, but most individuals were less than 15 years of age. Their length varied from 41-95 cm for males and 53-121 cm for females. The youngest and smallest sexually mature females were 7 years old, and the oldest and largest immature ones were 26 years old, giving a mean maturity age of 15.3 years in Norwegian waters. Our study shows that spurdogs use Norwegian coastal waters for their whole life cycle.

#### **SOME GOOD NEWS ON POPULATION RECOVERY**

Our research shows that younger age groups are currently dominating the spawning stock, due to an increase in recruitment of “young adults” which are those sharks not fully recruited to the stock until after the ban on direct fishery. In addition, our analysis indicated a much steeper increase in year-class strength for this series of year classes than estimated in the current ICES assessments, and, therefore, potential for a much swifter recovery of the spurdog stock.

The importance of fishery for population development is strongly dependent on which parts of the population are fished. Spurdog, like many other shark species, is considered particularly vulnerable to overexploitation, and therefore needs to be managed carefully. However, it is also often regarded as a problem species: because of its abundance, its spines, and its sandpaper skin, it can create problems for fishing for other species. With increased knowledge of the catch composition, important life history parameters and how the stock utilises Norwegian waters, more targeted management measures can be implemented, such as area and seasonal restrictions. Such restrictions affect other fisheries to a lesser extent and at the same time protect the spurdog stock, ensuring its continued recovery. ■

#### **ACKNOWLEDGEMENTS**

We would like to thank the many workers at several Norwegian landing sites for their cooperation in the sampling programme, as well as the experienced technical staff of the Institute of Marine Research for their dedicated workup of samples in the lab.

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#### **FURTHER READING:**

Albert OT, Junge C, Myrland MK (2019) Young mums are rebuilding the spurdog stock (*Squalus acanthias* L.) in Norwegian waters. ICES Journal of Marine Science, fsz156. doi:10.1093/icesjms/fsz156

Armstrong Moore E (2017) Many Sharks Live a Century—Longer Than Thought. National Geographic. <https://www.nationalgeographic.com/news/2017/11/sharks-age-longevity-lifespan-oceans>

Havforskningsinstituttet (Institute of Marine Research), temasider: pigghå. <https://www.hi.no/hi/temasider/arter/piggha> (Information in Norwegian)

Fiskeridirektoratet (The Norwegian Directorate of Fisheries) <https://www.fiskeridir.no> (Information in Norwegian)

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Karine Nigar Aarskog // UiT The Arctic University of Norway

# ARCTOS – a silver lining that emerged from a dark cloud

## SCIENCE AND SOCIETY

The Arctic Marine Ecosystem Research Network (ARCTOS) was conceived when two marine ecologists from Norway were unable to fly out of Canada after 11 September 2001. This network would ultimately prove highly beneficial for Arctic research in Norway.

**H**ALF AN HOUR AFTER THE SECOND AIRCRAFT CRASHED into the World Trade Center in New York, Professor Paul Wassmann from UiT The Arctic University of Norway was giving a lecture about the Barents Sea at a major conference in Quebec. News of the terrorist attack reached him and the other participants during their coffee break. As one consequence of the attack, commercial air traffic was suspended, and Wassmann and his fellow researcher Stig Falk-Petersen were unable to travel home for a week.

They spent the next five days listening to Canadian researchers talking about how Canada creates integrated, national research plans for the Arctic under the Canadian Arctic Shelf Exchange Study (CASES) research programme.

“This prompted us to think through Norway’s activities in the Arctic and ask ourselves if Norwegian research institutions could improve their cooperation and thus make an even better contribution to research on marine ecology in the High North,” says Wassmann.

They concluded that Norway had an excellent research environment, allocated substantial sums of money to Arctic research, and had great ambitions. However, there was one major challenge.

“There were so many cooks that the broth was spoiled. Norway’s institutions had divided the Arctic into spheres of interest, and there was little cooperation between them. Like Canada, we needed a network that could bring together interested researchers from all these institutions,” says Wassmann.

At that time Stig Falk-Petersen, currently a researcher at Akvaplan-niva, worked at the Norwegian Polar Institute. He says the conference revealed to him how little the researchers from other countries knew about the Arctic research being done in Tromsø.

“We had only ourselves to blame, since no collaboration existed between our institutions in northern Norway. We had to do something about it,” says Falk-Petersen.



The annual meeting point for ARCTOS members is “ARCTOS Days”, usually held in mid-March at Sommarøya, west of Tromsø. Photo: Ulrike Grothe

### CLOSER COLLABORATION

When Wassmann and Falk-Petersen finally returned to Tromsø, they contacted Salve Dahle, managing director of Akvaplan-niva, who was interested in cooperation.

“Obviously our network would need to have a purely academic research component, with emphasis on a research school and education for the next generation, along with links to environmental management. But it would also require an applied perspective: how can the research be of use to society, business and industry? This is where Akvaplan-niva came in. Having all the important dimensions right from the start was the key to ARCTOS success,” says Dahle.

One important goal was for our researchers to write more comprehensive applications and obtain more funding for larger research projects. During the two years following the establishment of ARCTOS in 2002, external grants for marine ecology research projects increased from 10 to 60 million Norwegian kroner.

“We agreed to write applications both jointly and in competition with each other. Those whose attempts to obtain funding were unsuccessful became involved as junior partners of those who received grants. This had a great impact,” says Falk-Petersen.

Since ARCTOS started up, the University Centre in Svalbard, the Norwegian Institute of Marine



ARCTOS postdocs and students enjoying summer field work in Rijpfjorden, 2007. Photo: Leif-Arild Håhjem



The CLEOPATRA team having lunch outside in the sun at Bjørnehiet in Rijpfjorden (Nordaustlandet), 2007. Photo: Janne Søreide

Research and Nord University have all joined the network. Today ARCTOS is run by Professor Jørgen Berge from UiT.

“We realised that Norwegian research in the Arctic had no clout, that it was fragmented and divided. If we want to be seen and have a stronger impact, we need to work together - and by doing that, we benefit each other. We’ve established many projects over the years,” says Berge.

#### OPEN NETWORK

At the heart of ARCTOS is the concept of having an altruistic network, open for anyone with a relevant professional interest. Among other things, this network has helped educate a new generation of researchers at its research school for PhD students. Eva Leu, who is currently a senior researcher at Akvaplan-niva and a member of the ARCTOS Secretariat, has been involved in the network right from its inception. She was one of the first doctoral students to participate in the ARCTOS PhD School, which has so far educated a total of 55 PhD students. Leu says the network has been very important for her in her capacity as a researcher.

“The fact that I’ve become acquainted with other researchers through ARCTOS has been decisive for me in my scientific work. Attending the PhD School and getting involved in the network at an early stage in my career gave me a good start, because I knew who I could contact later,” says Leu.

She believes that ARCTOS is particularly important for young researchers, who often go through a difficult phase between the end of their postdoc and their first permanent jobs as researchers.

“ARCTOS is a meeting place where new doctoral students can expand their horizons and get a clearer idea about current events in Arctic research. Being invited to attend meetings and activities through ARCTOS was what kept me alive. A network like this helps you through the best and worst aspects of scientific life,” she says.

According to Leu, one of the unique things about ARCTOS is its open, trusting atmosphere.



Eva Leu (left) and Janne Søreide.  
Photo: Ulrike Grothe

“This is thanks to the personalities of the founders of ARCTOS. They are good at sharing networks and bringing people together. I have tried to live up to this tradition and ask new, young researchers what I can do to help them,” says Leu.

Paul Wassmann says that he, Falk-Petersen and Dahle made use of their own networks to expand ARCTOS’ national and international networks.

“There are significant political and personal differences between us, but we all want to achieve something. Our own personalities and special interests should not be allowed to stand in the way of collaboration. We educated all the students and PhD fellows who joined the ARCTOS PhD School over the years. We found many practical solutions,” says Wassmann.

“When we merged our personal contacts, we had a network that included 30 international institutions,” adds Falk-Petersen.

#### HIGHLY ACTIVE

Eva Leu believes that ARCTOS has provided Norwegian Arctic research with precisely the sort of visibility that was required. The network can also take a lot of the credit for Tromsø’s annual international research conference, Arctic Frontiers. The conference was held for the fourteenth time this year (2020) and has become an important meeting place to discuss research, industry and politics. In connection with Arctic Frontiers, ARCTOS has been in charge of the Young Scientist Forum, which aims its activities at young researchers.

“Our PhD School and the Young Scientist Forum are probably the most important tools we currently have available to foster collaboration between marine ecologists in the institutions involved,” says Falk-Petersen.



ARCTOS Young Scientist Forum PhD course held in Svolvær in 2018 and led by Paul Wassmann. *Photo: Asle Guneriussen*

ARCTOS also initiated the High North Academy programme for PhD students, which was taken over by UiT and is currently being run by the Faculty of Biosciences, Fisheries and Economics. Since the network started, ARCTOS has worked actively on communicating with the general public, for example by arranging opportunities for journalists and artists to join expeditions.

“We have organised PolArt seven times in cooperation with the Tromsø Centre for Contemporary Art. Four artists have come along on expeditions each year over these seven years. We have also brought along musicians from Barcelona,” says Falk-Petersen.

Both Jørgen Berge and Paul Wassmann point out that, without ARCTOS, it would have been difficult to run large research projects such as the Nansen

Legacy, and that such projects might not even have been initiated.

“The network is the ‘benevolent spirit’ who works behind the scenes without demanding much attention. The spirit behind ARCTOS is the same one who personifies the Nansen Legacy,” says Wassmann.

Jørgen Berge believes that ARCTOS has developed into a robust, viable network, and he describes the group as unique.

“ARCTOS is helping us all in the long term. We are working in the background and are keeping people together. Over time, many researchers have come to see the value of sticking together and collaborating, independently from their institutions,” says Berge.





Paul Wassmann (left) and Stig Falk-Petersen.  
Photo: Karine Nigar Aarskog

## STRONGER TOGETHER

Salve Dahle adds that the network has also acquired an important role as a knowledge base for researchers. Thanks to ARCTOS, they are always aware of the expertise and research resources available when discussing potential international cooperation.

“The fact that researchers know what they themselves and others in the network have to offer is one of the most important things about ARCTOS. Working together, we can achieve more than we would have done individually,” says Dahle. Eva Leu can confirm this. She says she still derives great benefits from the network because she currently works in Oslo and does not have her Tromsø colleagues around her on a daily basis. “ARCTOS has enabled me to engage in dialogues with international partners because I have a larger platform than I would have had if I was operating on my own,” says Eva Leu. ■

## FACTS ABOUT ARCTOS:

- Seventy members from UiT The Arctic University of Norway, the Norwegian Polar Institute, Akvaplan-niva, the University Centre in Svalbard, the Norwegian Marine Research Institute and Nord University.
- Jørgen Berge (UiT) is the director, and Paul Renaud (Akvaplan-niva) is the deputy director.
- Has a secretariat and a board which represents its member institutions. Ulrike Grote is employed as the ARCTOS Secretary at UiT.
- The member institutions contribute NOK 30 000 each year.
- Each year, ARCTOS organises between four and six academic seminars with external lecturers, one PhD course in Lofoten, and ARCTOS Day on Sommarøy.

## ARCTOS' STRATEGY SETS THE FOLLOWING GOALS FOR THE NEXT FEW YEARS:

- be a world-leading network for marine research connected to the marginal ice zone and other habitats unique to the Arctic
- be recognised internationally for its excellence in Arctic marine ecosystem research, providing a holistic insight into the future ecosystem processes
- become an international focal point for education, training, and integration across the pan-Arctic domain, and an important contributor of knowledge for environmental management of the Arctic
- achieve a Centre of Excellence and one new National PhD School network

Visit the ARCTOS website at: [arctos.uit.no](http://arctos.uit.no)

Hector Andrade and Lionel Camus // Akvaplan-niva

Damien Tran and Pierre Ciret // CNRS and University of Bordeaux, UMR EPOC 5805, Arcachon, France

# Biosensors in the Arctic: bivalves for real-time marine monitoring

## RESEARCH NOTES

Monitoring the quality of ocean water is important, for various societal, economic and ecological reasons. But it is also costly and time-consuming, and the monitoring task itself can sometimes put humans at risk. We are looking for better ways to monitor water quality in high-risk environments.

**T**RADITIONAL SYSTEMS FOR MONITORING water quality in aquatic environments are rather expensive and rely on intensive exploitation of human resources to collect samples, do chemical analysis, and measure toxicity. This is especially true in the Arctic, where environmental conditions can be harsh, particularly in the winter due to low temperatures and poor availability of light. A desirable solution is to develop systems that can work without hands-on human control, either as sensors by themselves or as early warning detectors to trigger a sampling campaign.

In 2012, researchers from Akvaplan-niva AS and EPOC, a research unit of the University of Bordeaux and the French National Centre for Scien-

tific Research, teamed up to deploy a valvometer - a device that monitors the gaping behaviour of bivalves - in Ny-Ålesund, Svalbard. The aim of this deployment was to adapt this biosensor developed by EPOC to Arctic conditions in order to study how the Icelandic scallop *Chlamys islandica* behaves and how its biologic rhythms are adapted to the Arctic environment. A new deployment with blue mussels *Mytilus sp.* was carried out in 2016 to study that species' biology. The blue mussel had disappeared from Svalbard, but due to climate warming, it has re-settled since the beginning of the 2000s.

To monitor the bivalves' activity directly in the field, the valvometer is installed inside a cage.



Icelandic scallops (top) and blue mussels (bottom) are ready to be deployed in the field with the electrodes glued onto their shells. *Photos: Damien Tran*



Hector Andrade (standing), Pierre Ciret (left) and Damien Tran prepare a cage with bivalves connected to a valvometer in Ny-Ålesund. *Photo: Carl Ballantine*



Hector Andrade preparing an exposure experiment to test the biosensor. *Photo: Lionel Camus*



Damien Tran gluing sensors to Icelandic scallops in the lab. *Photo: Carl Ballantine*

A pair of extremely light electrodes with flexible cables are glued on each half shell. An electromagnetic current generated between the electrodes makes it possible to measure the mollusc shell opening and closing. In a typical biosensor deployment, sixteen pair of electrodes are coupled to a waterproof box next to the animals, simultaneously recording the behaviour of sixteen bivalves. This box contains a circuit board that manages the electrodes and is connected by cable to a second circuit board at the sea surface or on land. The data are saved and digitised, and then transferred to a supercomputer. The system measures the bivalves' opening status every 1.6 seconds.

The continuous monitoring of Icelandic scallops and, more recently, blue mussels in Ny-Ålesund is allowing us to understand the baseline gaping behaviour and shell growth of both species and how changes in the environment affect the species' life cycles. A surprising discovery was that despite the lack of light during the polar night, both species continue to grow in winter, and maintain a daily cycle in their behaviour.

Once we have characterised baseline behaviour, we can study how stressors such as increased temperature or the presence of toxins in the water disturb the species' gaping behaviour. In 2020, we will expose Icelandic scallops to harmful algae under laboratory conditions, to test whether the species changes its baseline behaviour. If we manage to record behavioural changes that can be attributed to the presence of phycotoxins in the water, we will have developed a biosensor that can be employed as an early warning system to detect harmful algae blooms in the north. Such monitoring tools are much-needed nowadays, especially by the salmon aquaculture industry.

Future projects also include testing whether the biosensor coupled with a hydrophone can be employed to study effects of noise pollution in the sea. In this regard, this innovative tool holds promise for marine monitoring, allowing managers to assess environmental status of marine and freshwater ecosystems remotely and in real time. ■

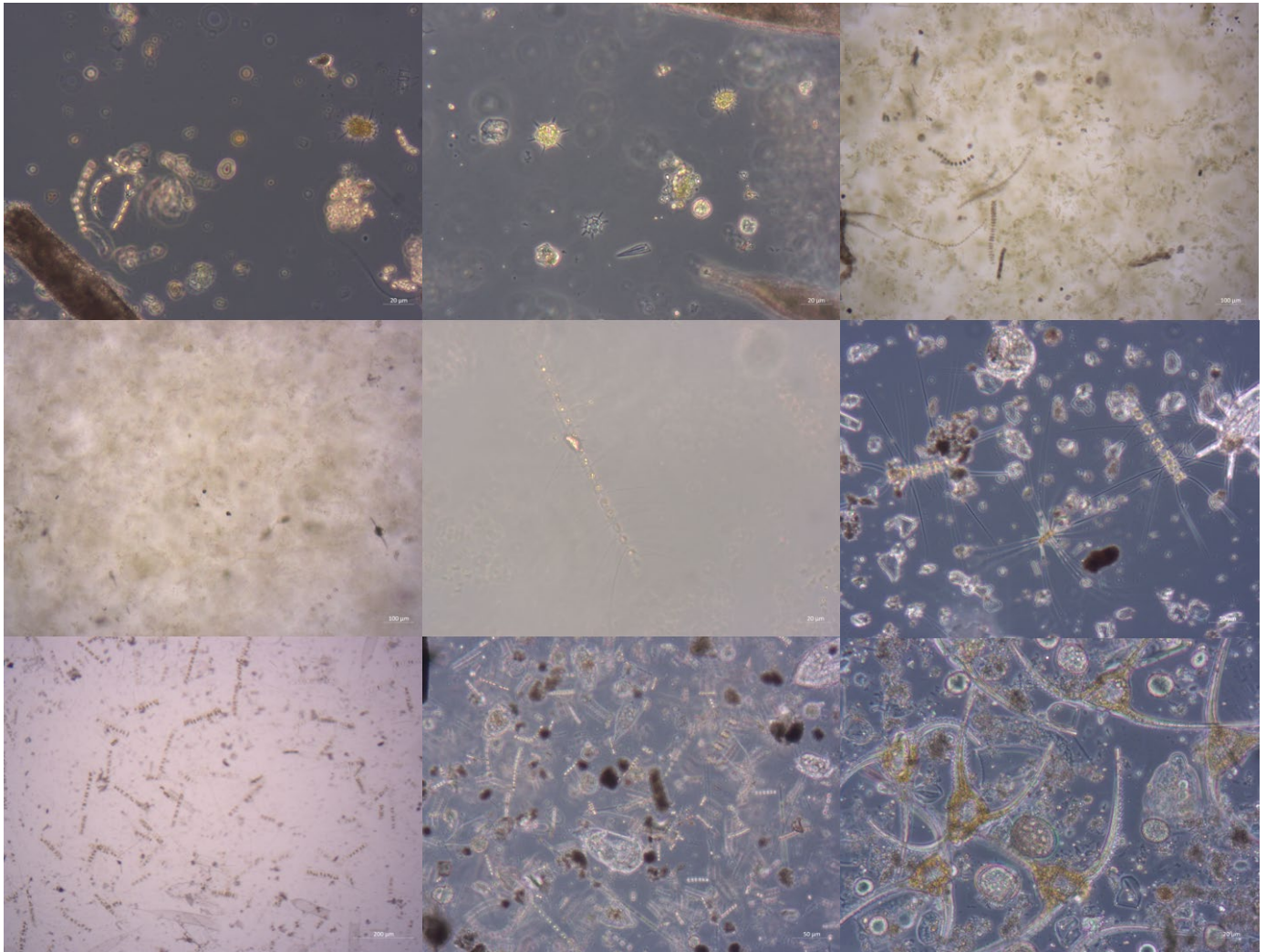
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#### FURTHER READING:

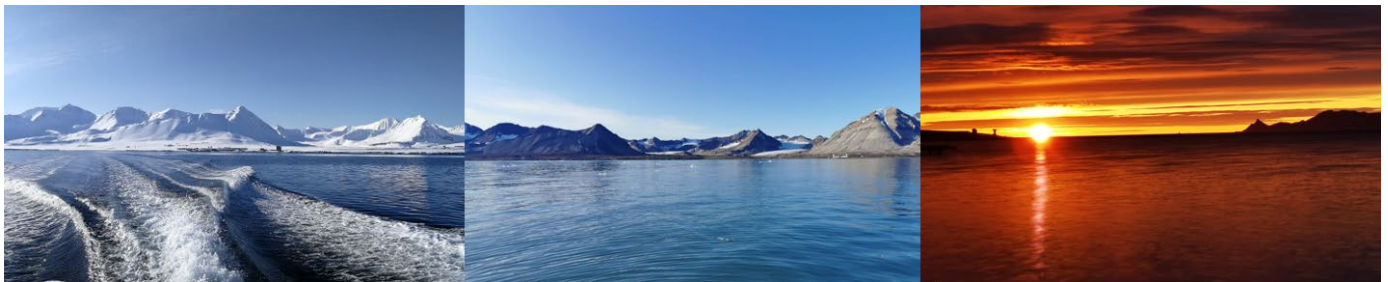
Andrade H, Massabuau J-C, Cochrane S, Ciret P, Tran D, Sow M, Camus L (2016) High Frequency Non-invasive (HFNI) Bio-Sensors as a potential tool for marine monitoring and assessments. *Frontiers in Marine Science* 3. <https://doi.org/10.3389/fmars.2016.00187>

Tran D, Sow M, Camus L, Ciret P, Berge J, Massabuau J-C (2016) In the darkness of the polar night, scallops keep on a steady rhythm. *Scientific Reports* 6, 32435. <https://www.nature.com/articles/srep32435>

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Light microscope pictures of phytoplankton samples from each of the nine ocean acidification experiments, illustrating changes in community composition from late April to early September. *Photos: Ane Cecilie Kvernvik / Norwegian Polar Institute*



Kongsfjorden landscape through the seasons (composite). *Photos: Ane Cecilie Kvernvik / Norwegian Polar Institute*

Allison Bailey, Ane Cecilie Kvernvik, Philipp Assmy, Anette Wold,  
Amalia Keck and Haakon Hop // Norwegian Polar Institute  
Clara Hoppe // Alfred Wegener Institute

# Arctic marine organisms responding seasonally to ocean acidification

## RESEARCH NOTES

Spring brings vast changes to the Arctic. The sun once again illuminates the sky after a dark, cold winter; snowdrifts shrink and melt, plants push through the barren ground and flowers emerge. In the sea, a less familiar, but equally important seasonal dance takes place.

**F**OR THE UNDERWATER WORLD, the yearly return of the sun melts and fragments the overlying sea ice, letting the sun's rays penetrate ever deeper into the upper water column. This kickstarts a plethora of chemical, physical and biological changes. For the miniscule but multitudinous plankton that comprise the bulk of life in the ocean, this is the start of a fast and furious period of growth and physiological change. Copepods just 3 mm long migrate hundreds to thousands of metres from their overwintering habitat at depth to the surface, where they mate and produce young, often doing so in the dark and still starving from the winter. Their food source, the many species of single-celled organisms composing phytoplankton, colour the surface waters with thousands of cells per drop of seawater, different

species' populations booming and busting in unison or succession. Changes in seawater salinity, acidity, temperature, and vital nutrients, all of which are important for marine plankton, also follow seasonal cycles.

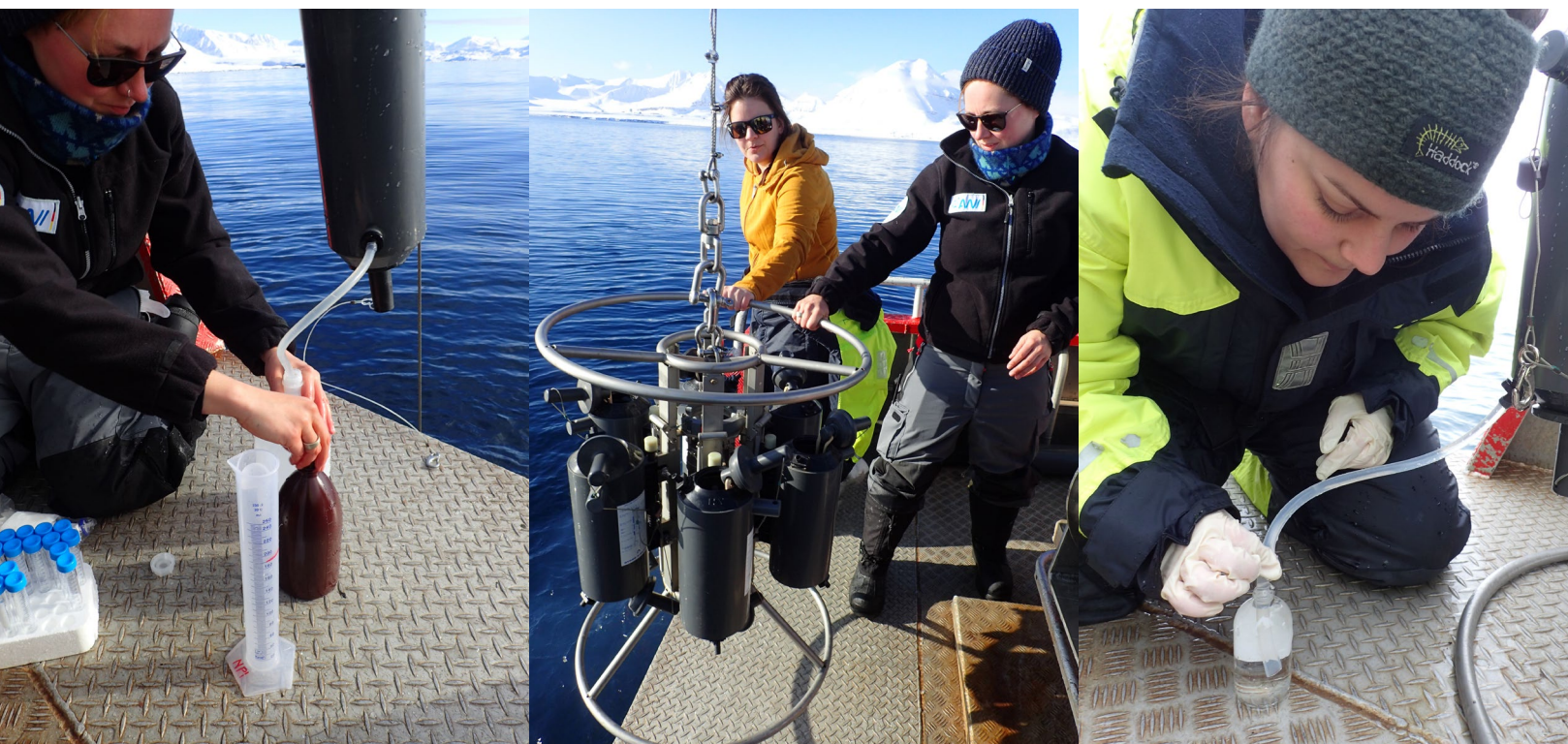
While significant and largely unstudied, the fine-scale seasonal changes in the Arctic marine ecosystem are also of utmost importance in our quest to understand how climate change and ocean acidification will affect this vulnerable region. While warming and acidification of seawater will affect the physiology of all marine organisms, the severity of their effects depends on many factors which vary by season: an organism's life stage and physiological state, the presence of their predators, competition from other species,

food availability and quality, and the abiotic environment. Therefore, investigations of how climate change and ocean acidification will affect marine organisms must necessarily be conducted throughout the year, to make sure we detect all the responses to environmental change and understand when the greatest responses will occur.

However, investigating the Arctic through all seasons is notoriously difficult due to the extreme weather, nature conditions, remoteness, and distance from infrastructure. Laboratory experiments, which are vital for quantifying how climate change and ocean acidification will affect marine

organisms, are also logistically challenging, often restricting experimental studies in the High North to a single point in time. However, the Ny-Ålesund Marine Laboratory in Svalbard provides an excellent site to achieve seasonal monitoring, with year-round access to Kongsfjorden and advanced laboratory facilities to conduct experiments on responses to climate drivers.

In 2019 we conducted a series of nine ocean acidification experiments that covered the entire growing season, from late April to early September, parallel to the initiation of a seasonal monitoring programme in Kongsfjorden, Svalbard, by the



The seasonal sampling campaign was carried out by Norwegian Polar Institute researchers in collaboration with researcher Clara Hoppe from the Alfred Wegener Institute, who has followed the spring bloom in Ny-Ålesund for several years. Here, on board MS *Teisten*, she collects seawater for chlorophyll and phytoplankton taxonomy analyses. *Photo: Allison Bailey / Norwegian Polar Institute*

Ane Cecilie Kvernvik (Norwegian Polar Institute) and Clara Hoppe (Alfred Wegener Institute) are interested in the changes in the phytoplankton species and physiology over the season. Here they deploy a water sampling rosette to collect seawater at different depths in early May in Kongsfjorden. *Photo: Allison Bailey / Norwegian Polar Institute*

Ane Cecilie Kvernvik carefully collects seawater for methane analysis. In total, 15 parameters were measured on a weekly basis from May to September, providing a detailed account of the biogeochemical processes occurring throughout the season. *Photo: Allison Bailey / Norwegian Polar Institute*



Norwegian Polar Institute. Our goal was to determine whether seasonal changes in water chemistry, plankton species composition, food availability, or organism physiology would influence how ocean acidification affects energy transfer at the base of the marine food chain: zooplankton grazing on phytoplankton. In each experiment, the natural assemblage of phytoplankton and copepods in the fjord was collected and exposed to increased carbon dioxide partial pressure ( $p\text{CO}_2$ ) in the lab, simulating ocean acidification. After four days, we measured the growth of the phytoplankton and the grazing rate of the copepods on the phytoplankton.

Interestingly, we found that the same experiment, repeated at different times throughout the year, provided different results. Early and late in the summer, simulated ocean acidification did not affect copepod grazing. However, during spring, when the phytoplankton was at peak bloom, copepods increased their grazing in response to high  $p\text{CO}_2$  (ocean acidification). These results are important as background information when interpreting other studies; this shows why there is a potential to make erroneous conclusions and miss detecting important effects if only one time point is studied.



The first sampling trip of the campaign: excellent weather, snow-covered mountains, phytoplankton still at low levels from the winter. Clockwise from back left: Andrea Faltynek (assistant at the Ny-Ålesund Marine Laboratory), Clara Hoppe (Alfred Wegener Institute), Allison Bailey and Ane Cecilie Kvernvik (both from the Norwegian Polar Institute). *Photo: Allison Bailey / Norwegian Polar Institute*

Postdoctoral researcher Allison Bailey is interested in how the changing phytoplankton and zooplankton communities in the fjord would affect the ecosystem's sensitivity to ocean acidification. Here, a net drawn through the water column collected live zooplankton, which were then transported to the nearby Marine Lab for experiments. *Photo: Clara Hoppe / Alfred Wegener Institute*

Our observation that ocean acidification coincides with increased grazing at peak bloom may indicate that there is an energetic cost to life at high  $p\text{CO}_2$  that copepods are able to compensate by increasing feeding when food is abundant, but not when it is scarce. Alternatively, the effect may be specific to the phytoplankton species that were present, the life stage or physiological status of the copepods, or the chemistry of the seawater at that time.

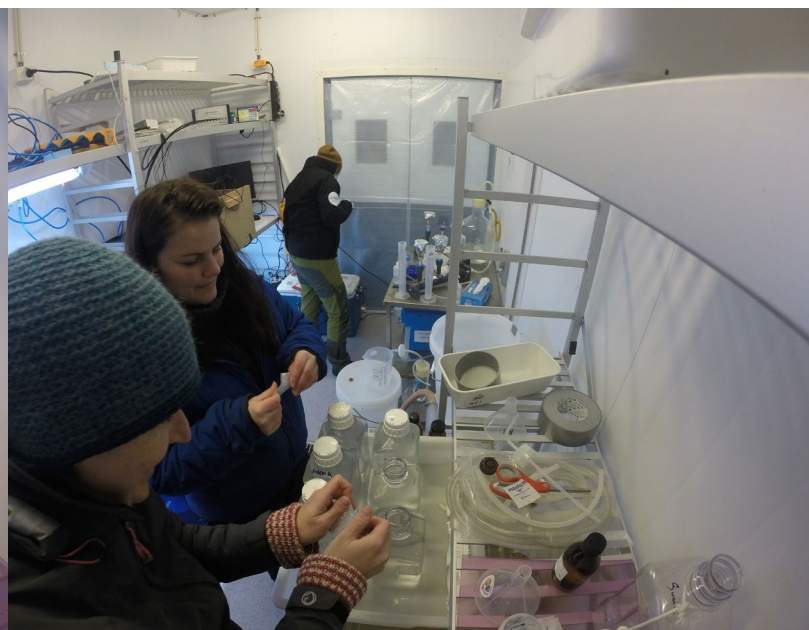
By examining the biological and chemical data collected from the fjord at the same time, we hope to resolve what drives the variation in ocean acidification effects we have observed, and thus what makes the marine ecosystem in Kongsfjorden more sensitive - or less sensitive - to ocean acidifi-

cation over time. Seasonal monitoring, combined with repeated experiments, allows us to continue asking important questions about ocean acidification:

- When during the year will marine organisms experience the strongest effects of ocean acidification?
- What point in their life span does this coincide with?
- As the mix of plankton species in the water column shifts throughout the year, which assemblages of species are most robust or most sensitive to ocean acidification?
- How will ocean acidification affect the carbon budgets of the upper ocean, from  $\text{CO}_2$  outgassing to food for upper trophic levels?



Live copepods are counted and preserved following an experiment measuring their feeding. *Photo: Allison Bailey / Norwegian Polar Institute*



Allison Bailey and Ane Cecilie Kvernvik prepare bottles with copepods and phytoplankton, which will be incubated for 24 hours and then analysed to measure how much phytoplankton the copepods consume. Some of the bottles have seawater directly from the fjord; others have seawater with increased  $\text{CO}_2$ , mimicking ocean acidification. *Photo: Allison Bailey / Norwegian Polar Institute*

Seasonal monitoring is also important for detecting shifts in the timing of biological events due to climate change. It also constitutes a crucial background for interpreting and comparing studies based on a single data collection point per year. By understanding the variability attributable to seasonality, we can be more assured in our analyses of interannual variation for ecosystem monitoring.

The Arctic and its ecosystems are currently experiencing some of the strongest effects of climate change, and it is vital to predict how Arctic organisms will respond to these changes. The strong seasonality in the Arctic will likely result in temporally variable responses to climate drivers, with important implications for the timing of

when marine ecosystems are most vulnerable to climate change and ocean acidification. Our study indicates that even weekly changes in the plankton community through the season affect whether or not an important trophic linkage is affected by simulated ocean acidification. There are likely many more seasonally dependent responses to climate change drivers. The extension of our investigations to the winter period is likely to reveal even more ecologically relevant variations in responses to warming and ocean acidification.

These studies were funded in part by Fram Centre Flagship “Ocean acidification and ecosystems effects in Northern waters” and the Norwegian Polar Institute’s Seasonal Pelagic Monitoring in Kongsfjorden. ■



Back on shore in the Ny-Ålesund Marine Laboratory, freshly caught phytoplankton and copepods from the fjord were kept in aquaria in a cold room that replicates the conditions of the fjord, with one difference: some of them were exposed to CO<sub>2</sub> levels predicted for 2100. Increased pCO<sub>2</sub> makes the seawater more acidic (lower pH), a process called ocean acidification.

*Photo: Allison Bailey / Norwegian Polar Institute*

Allison Bailey, Ane Cecilie Kvernvik and Clara Hoppe check the aquaria in the cold room, which was kept at around 2°C throughout the summer.

*Photo: Allison Bailey / Norwegian Polar Institute*

Jesamine Bartlett and Kristine Bakke Westergaard // Norwegian Institute for Nature Research, Trondheim

# Arctic Aliens: A rising threat

## RESEARCH NOTES

The Arctic is the fastest warming region on Earth: ice is melting faster than ever, exposing land that is ripe for colonisation and occupation by both native and invading species. But it is not only flora and fauna that are travelling north: so are we. *Homo sapiens*, the greatest invader of them all.

**G**LOBAL BIODIVERSITY IS UNDER ATTACK, especially from alien species, climate change, and changes in land use. And where these threats converge - as they do in the Arctic - the consequences for local ecosystems will be hardest felt. Human activity in the polar regions is at record levels, with over 45 000 people visiting Antarctica in 2017/18, and tourism is now a pillar for local economies in remote Arctic communities such as Longyearbyen in Svalbard and settlements across Greenland. Svalbard in particular has seen an unprecedented rise in tourism, with over 73 000 guest arrivals in 2018. That is 30 000 more tourists to one island in the Arctic than visited the whole of the Antarctic continent during the same year. In 2018, the largest proportion of these guests arrived on cruise ships, accounting for

46 000 individuals. Meanwhile, 81 000 people had arrived at Longyearbyen airport by the end of September 2019. And there is no sign of these numbers slowing, with investment in the town geared to tourists, and an ever-increasing fleet of expedition cruise ships and companies.

Whilst many of us visiting these remote places take care to ensure we “leave no trace”, we do not account for what we unwittingly transport. An examination of the footwear of 259 air travellers coming through Longyearbyen airport found an average of 3.9 seeds on each person. This amounts to 270 000 seeds imported into Svalbard every year, a quarter of which are able to germinate under conditions found in Svalbard. In Barentsburg, the paths walked by visitors each summer

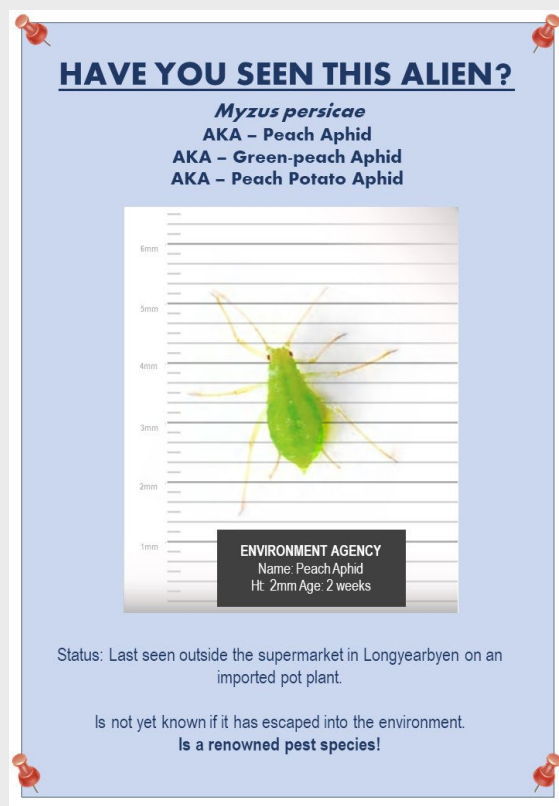


are flanked by weeds scattered by humans. In a landscape that is otherwise stark and barren, the verges of paths are verdant green.

Although the Svalbard Environmental Act prohibits the intentional introduction of alien species to the region, there is currently little regulation on the imports of plants and fodder into Svalbard. This, in addition to increasing human activities, heightens the risk of unintentional introductions, and is now cause for growing concern amongst decision-makers. Ornamental plants are imported to Longyearbyen's grocery store for local residents, yet whilst the plants themselves could not survive life outside of someone's living room, hitchhikers on them may be able to. A survey of imported pot plants that were outside the only supermarket in

Svalbard during summer 2018, when temperatures are above freezing, found the green-peach aphid *Myzus persicae* to be happily occupying three different ornamental plants. This aphid is a known pest species, with a cold-tolerance physiology that may just allow it to colonise the area. Whether or not it has managed to do so remains to be seen.

Imports to Svalbard have occurred now for decades, most notably, to the settlements of Barentsburg and Pyramiden which have previously held significant communities of 1000 people each. Both towns were deliberately planted with imported grasses to "green" the communal areas and make residents feel more at home. Though the people may have left over the years, non-native plants



Passengers waiting for their luggage at Longyearbyen airport meet this unusual environmental protection officer in a video about preventing influx of alien species to Svalbard. Image © Klipp og Lim

like *Deschampsia cespitosa* still remain. Not only did the communities import plants for decoration, but they also imported farm animals to support the human population. The animals themselves were kept in stables, but their dung, bedding, and waste fodder were all thrown outside, creating mounds of fertile soils that also contained seeds. Now, you can find some of the most diverse and lush vegetation in all of Svalbard in and around these old farms. There, *Barbarea vulgaris*, winter cress, reaches over a metre in height, flowers, and reproduces. *Taraxacum officinale*, the common dandelion, is so abundant in places that there are too many plants to count and the landscape is yellow with flowers in summer. In the main town of Longyearbyen, a similar planting scheme in the past is why lawns of *Festuca rubra* can now be found lining some roads.

Whilst these farms are now abandoned and the pigs and cows long gone, the problem of animal husbandry in Svalbard has not gone away. With the rise in tourism has come a rise in dog yards. Year-round dog sledding through the beautiful valleys in and around Adventdalen, near Longyearbyen, has become a main activity choice for visitors to the area. A new dog yard has now been established in Barentsburg, and another is likely in Pyramiden in the future. In 2019, approximately 500 dogs are owned by the four main sledding companies, and as many as 20 new puppies are born in the larger dog yards each year. The dogs, like the farm animals, fertilise adjacent ground and unusually green vegetation surrounds the kennels as a consequence. Like the old farms, dog yards use hay and straw rich in seeds to bed the animals through the cold.

Recent surveys of invasive plant species in the Longyearbyen and Adventdalen area found strong correlations between animal husbandry and alien plant species. We do not yet know what invertebrates or microbes may be imported too, but for now the impact from plants and nutrients alone is evident. Alien species, both plants and animals, tend to outcompete native species for everything from space to nutrients, and even sunlight. Invasions are one of the biggest threats to global biodiversity, after all, and now Svalbard must learn this lesson, just like the rest of the world.

## A GREENING BARENTSBURG – SUMMER 2019



As climate change makes the harsh winters and cool summers of the Arctic increasingly favourable to any hitchhiking species, as the retreat of ice opens up more soils for colonisation, and as human activities fertilise the barren ground, we can no longer turn a blind eye to the issue of alien species in even the most inhospitable areas of our planet. If we are to maintain the Arctic as a place that is world-renowned for its unique ecology and landscapes, then actions must be taken to protect it. Whilst long-term societal changes are needed to turn the tide of climate change, political decisions that will increase biosecurity and personal responsibility in Svalbard can be taken with comparative ease and rapidity. If you choose to travel north, check your own clothes and equipment for seeds and stowaways, and visit

[www.stoparcticaliens.com](http://www.stoparcticaliens.com) for more information on what you can do to ensure that your footprints are just that.

Visiting the polar regions can be a life-changing experience, and teach visitors a lot about the planet, the environment, and why it is worth protecting. But remember that in a world where we cannot survive without significant protection from the elements, we are aliens too, and where we go, other aliens tend to follow... ■



Full-scale automatic weather stations are core infrastructure in COAT's climate monitoring network. The weather stations are "hot-spots" for potential co-location and expansion of measurements to cover a wider range of variables related to both the biosphere and cryosphere within COAT and the Svalbard Integrated Arctic Earth Observing System (SIOS). Data from the weather stations can be downloaded from eKlima ([eklima.met.no](http://eklima.met.no)). *Photo: Ketil Isaksen*



Eeva Soininen and Rolf A Ims // UiT The Arctic University of Norway

Åshild Ø Pedersen // Norwegian Polar Institute

Audun Stien // NINA – Norwegian Institute for Nature Research

# Climate-Ecological Observatory for Arctic Tundra – Status 2020

## RESEARCH NOTES

The Arctic tundra is challenged by climate change — more so than most other ecosystems on Earth. The rapid shifts to new climate regimes may give rise to new ecosystems with unknown properties. These dramatic changes call for ecosystem-based monitoring of climate impacts on Arctic food webs.

**T**HE CLIMATE-ECOLOGICAL OBSERVATORY FOR ARCTIC TUNDRA (COAT) is a response from five Fram Centre institutions to international calls to establish scientifically robust observation systems that enable real time detection, documentation, and understanding of climate impacts on Arctic tundra ecosystems.

### ECOSYSTEM-BASED MONITORING AND RESEARCH

COAT is a system for long-term research with focus on the Low-Arctic Varanger Peninsula and the High-Arctic Svalbard. It combines state-of-the-art climate-ecological research with management. The focal COAT regions provide contrasts in system complexity, climate and management regimes. COAT builds on and expands the ongoing research and long-term monitoring in both regions.

### FOOD WEB MODELS AND MODULES

COAT aims to establish causal relations between components of the food webs that are important to ecosystem functioning and management, and how climate and management actions impact these relations. The likely paths for such causal relations are expressed in terms of conceptual “*climate and management impact path models*”. These models encompass tightly linked clusters (termed *modules*) of organism groups that are expected to be directly or indirectly impacted by the same set of climate and management drivers. The purpose of the conceptual models is to form a framework for data-driven causal analyses and predictions of climatic effects, and further infer how management could be effective in mitigating predicted unwanted effects (see example on p 61).



Spring foraging (grubbing) by pink-footed geese has changed the composition, structure and function of the vegetation community. Photo: Cornelia Jaspers

## MONITORING, ANALYSES, ADAPTIVE UPDATES

The COAT science plan (download from [www.coat.no](http://www.coat.no)) describes the overall approach, background knowledge, climate impact path models, and the monitoring design. The study methods include both ground observations, automatic data recording and remote sensing. The plan also describes the *adaptive* monitoring approach of COAT: How new knowledge, technology, science questions and management intervention will be incorporated into models and monitoring designs in an iterative manner - a process in which stakeholders and management authorities may be engaged (see example on p 61). As part of adaptive monitoring, COAT also develops new monitoring technologies and new data analyses and modelling tools.

## COAT INFRASTRUCTURE IN THE FIELD

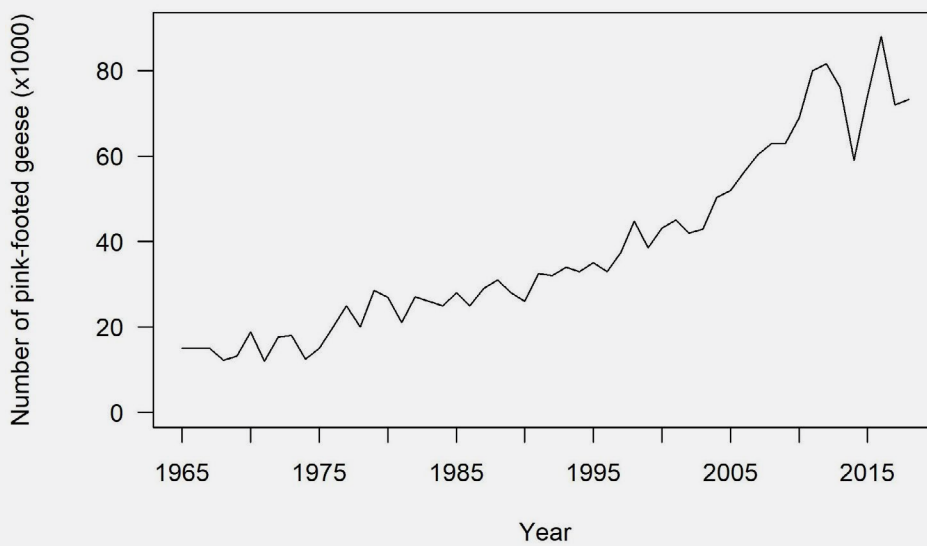
In 2016, COAT started to implement research infrastructure related to *data capture* (i.e. gathering information related to both food webs and climate), *field logistics* and *data management solutions*.

To cover the range of existing variation in climatic and management contexts, COAT data sampling systems are geographically distributed. The first five COAT weather stations were set up in 2018-2019, in inland regions of Svalbard and across one coast-to-inland gradient at Varanger. Five more will be set up in Svalbard in 2020-2021. Other types of infrastructure that have been established are herbivore exclosures, networks of camera traps and acoustic sensors, telemetry equipment, drones, and networks of small instruments that log climate parameters. These are distributed at spatial and temporal scales appropriate for estimating the weather patterns and ecological interactions of interest in the COAT modules.

Field logistics is essential for the large COAT field crews that operate in remote tundra areas in Varanger Peninsula and Svalbard. As part of the infrastructure project, COAT Varanger has established local storage facilities in Vadsø, acquired

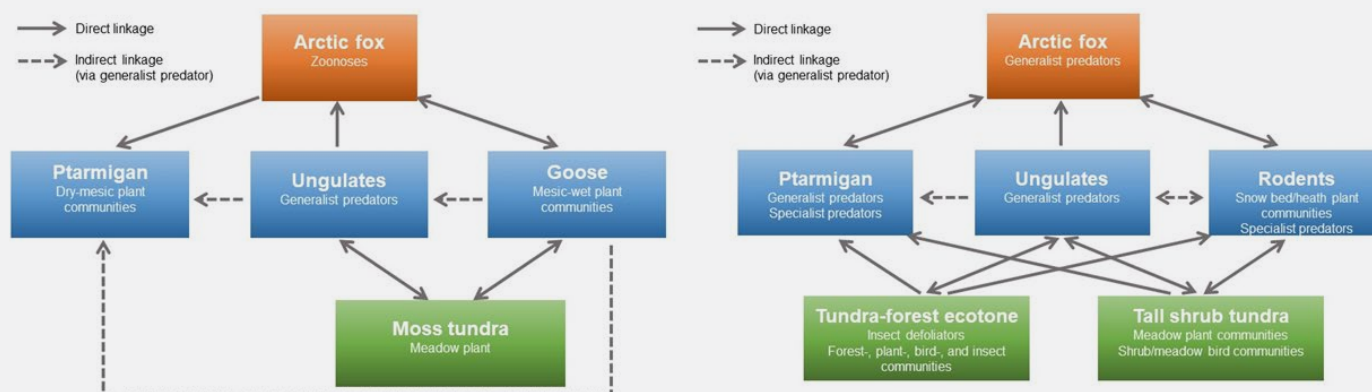


Drones are important infrastructure to monitor landscape disturbances caused by geese. Photo: Virve Ravolainen



The pink-footed goose population has increased substantially during the last decades.

Graph modified from the AEWA international single species management plan



The food webs in Svalbard and on the Varanger Peninsula are represented by five and six monitoring modules, respectively. Examples of linkages within the modules include predator–prey and plant–herbivore interactions or competitive interactions. The monitoring targets in each module are listed within the boxes and the target that gives each module its name is written in bold.

transport units (snowmobiles, ATVs, car), and in fall 2019 established a permanent field station. COAT Svalbard field operations are organised under the umbrella of Norwegian Polar Institute logistics.

### COAT DIGITAL INFRASTRUCTURE

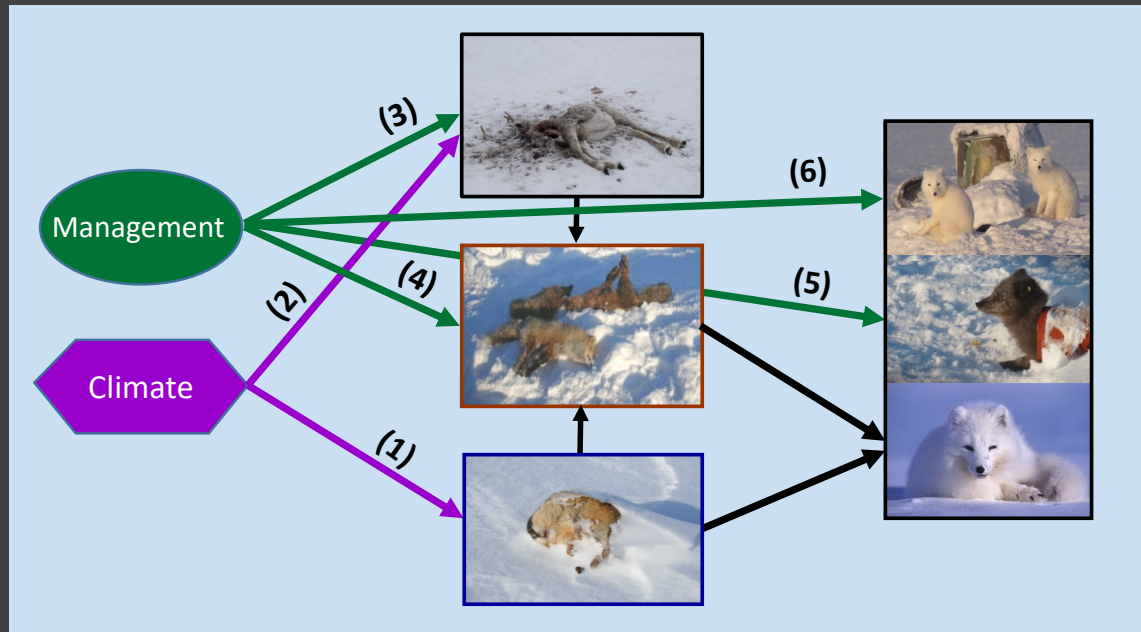
A data management system is a crucial part of the COAT infrastructure. The COAT data portal will gather all primary data from COAT, providing open access to external users. Work with the COAT data portal has advanced to testing of the first version. Concurrently, the COAT team is working with establishing data format standards, organising and documenting datasets, and developing transparent and reproducible data pipelines for activities ranging from taking field notes to monitoring state variables. An open version of the data portal will be released in 2020 with access through the COAT web pages. ■

### FURTHER READING:

Ims RA, Killengreen ST, Ehrich D, Flagstad Ø, Hamel S, Henden J-A, Jensvoll I, Yoccoz NG (2017) Ecosystem drivers of an Arctic fox population at the western fringe of the Eurasian Arctic. *Polar Research* 36: DOI:10.1080/17518369.2017.1323621

### COAT PARTNERS

- Norwegian Institute for Nature Research
- Norwegian Meteorological Institute
- Norwegian Polar Institute
- University Centre in Svalbard
- UiT The Arctic University of Norway



#### THE VARANGER ARCTIC FOX MODULE – AN EXAMPLE OF THE COAT ADAPTIVE MONITORING

The Arctic fox is the only mammalian predator endemic to the terrestrial Arctic. Over the last century, Arctic fox populations have declined steeply in the southernmost parts of their range, including the Varanger Peninsula.

The conceptual model for the Arctic fox module includes the two climate impacts paths likely involved in the population decline. Both are due to icier snowpack in warmer winters increasing mortality in herbivores. Path 1 describes how a decrease in the abundance of a key prey (lemming) implies lost opportunities for Arctic fox reproduction. Path 2 describes how abundant reindeer carrion subsidises an increase in the population of red fox (key natural enemy), which ultimately implies competitive exclusion of the Arctic fox. Analyses of 15 years of monitoring data have provided evidence for both of these paths (see further reading).

The conceptual model originally included two potential management intervention paths (see [www.coat.no/en/Arctic-fox/Varanger](http://www.coat.no/en/Arctic-fox/Varanger)). Path 3 involves reindeer management to reduce the amount of reindeer carrion by reducing the size of herds, while path 4 involves culling the population of red fox. Culling of red fox was implemented in 2005. Although it had some positive effect on the use of the area by Arctic fox, this management intervention was not sufficient to rescue the Arctic fox population, which was estimated at only five individuals in 2016 (Ims et al 2017).

The Arctic fox module has a reference group (consisting of researchers, stakeholders and management authorities) that advised the Norwegian Environment Agency in 2017 to implement two additional management interventions. Consequently, during 2018 and 2019 a total of 53 captive-bred Arctic foxes were released (path 5) and supplementary food (path 6) was provided at Arctic fox breeding dens.

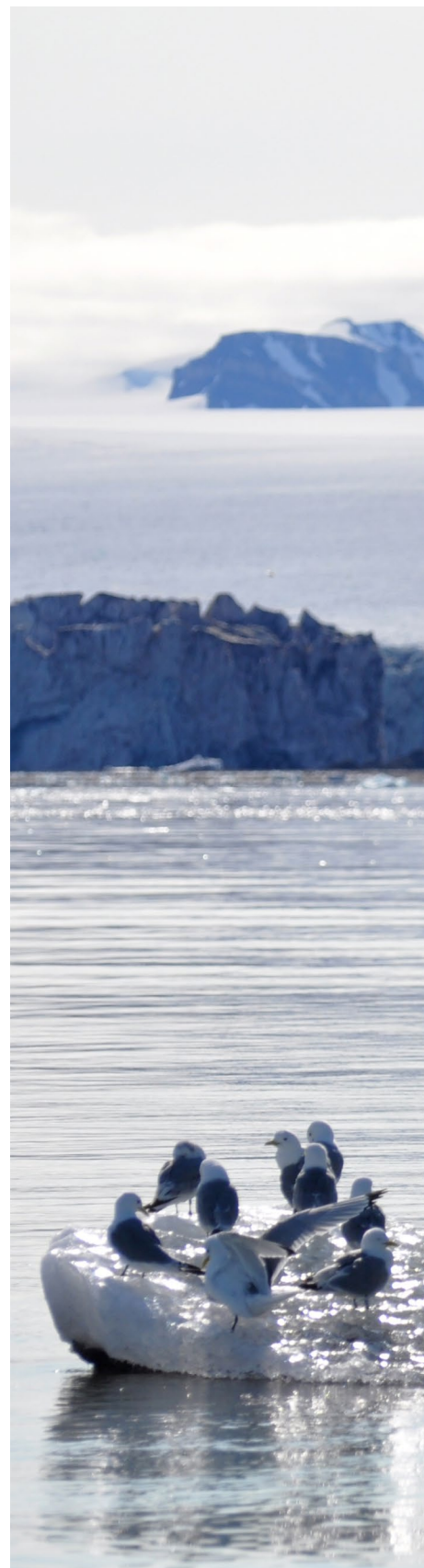
Ingjerd Sunde Krogseth and Christine Solbakken // NILU – Norwegian Institute for Air Research  
Trude Borch // Akvaplan-niva

# How to COPE? Contaminant–climate change interactions in the Arctic

## RESEARCH NOTES

Changes in climate. Loss of biodiversity. Emissions of toxic contaminants. These are the main environmental challenges we face today, and few places are they felt as strongly as in the Arctic.

Eider ducks, black-legged kittiwakes and glaucous gulls have been studied in Kongsfjorden for many years, and time-series of contaminants in these species will be central in COPE to increase our understanding of contaminant–climate change interactions on Arctic top predators. *Photo: Geir Wing Gabrielsen*







**A**RTIC ECOSYSTEMS ARE SUBJECT to multiple pressures, of which climate change and exposure to long-range transported, persistent, bioaccumulative and toxic contaminants are two of the major challenges. How do the Arctic ecosystems cope with this? And how do we cope with it as scientists? This is the key focus in a new cross-disciplinary project run by Fram Centre institutions.

Persistent organic pollutants (POPs) and chemicals with similar properties are transported to the Arctic from source regions further south. In the Arctic, POPs are taken up in the ecosystems and accumulate through the food web, resulting in high concentrations in top predators. In parallel with this, the Arctic experiences strong and rapid changes in temperature and climate, with effects such as loss of sea ice and inflow of Atlantic water. This also impacts Arctic ecosystems, including top predators such as polar bears and Arctic-breeding seabirds.

Some of the key project participants in COPE (from left): Gary Griffith (Norwegian Polar Institute), Sabine Eckhardt (NILU – Norwegian Institute for Air Research), Knut Breivik (NILU), Heli Routti (Norwegian Polar Institute), Kjetil Sagerup (Akvaplan-niva), Jan Ove Bustnes (Norwegian Institute for Nature Research), project leader Ingjerd S Krogseth (NILU), Lovise Pedersen Skogeng (NILU), Anita Evenset (Akvaplan-niva), and Geir Wing Gabrielsen (Norwegian Polar Institute).  
*Photo: Trude Borch*

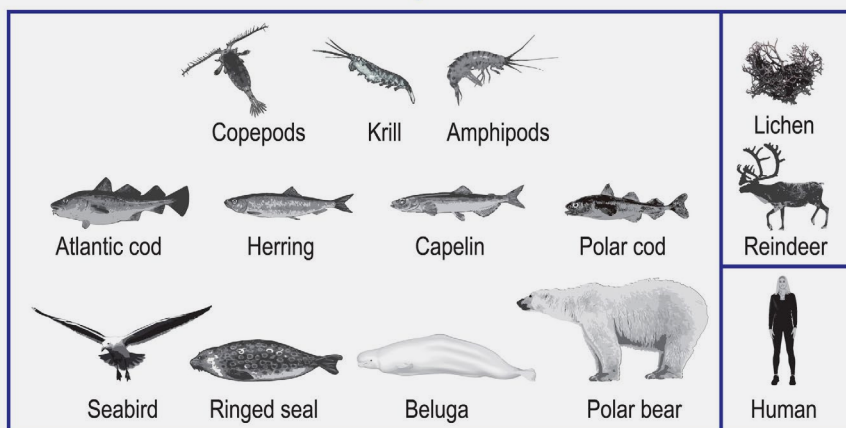
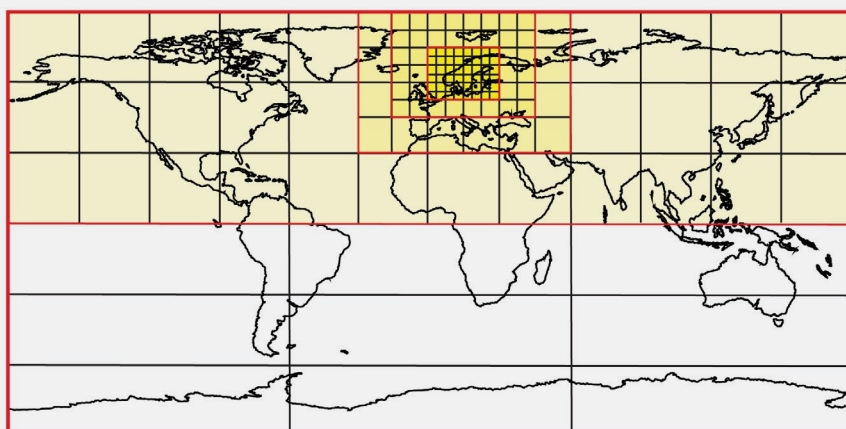
The Fram Centre Flagship “Hazardous substances – effects on ecosystems and human health” has for many years done in-depth field-based research on contaminants in the European Arctic ecosystems, including initial studies of their interactions with climate change. Given that it is a challenge trying to understand how Arctic ecosystems are affected by either contaminant exposure or climate change in isolation, our understanding of the combined effects of these pressures is still very limited.





Polar bears and glaucous gulls in Kongsfjorden, Svalbard. These Arctic top predators are subject to both high concentrations of contaminants and ongoing climate changes, with yet unknown consequences. Like the top predators, eider ducks in Kongsfjorden have been monitored for many years. *Photos: Geir Wing Gabrielsen*





The Nested Exposure Model (NEM) integrates environmental transport and fate of organic contaminants in the physical environment (top) with bio-accumulation in Arctic food webs (bottom). *Copyright: NILU*

**COPE** – “Integrated risk assessment framework for evaluating the combined impacts of multiple pressures on Arctic ecosystems” (2019-2023) is funded by the Research Council of Norway (#287114).

The project is led by NILU – Norwegian Institute for Air Research, in close cooperation with the Norwegian Polar Institute, the Norwegian Institute of

Nature Research, Akvaplan-niva AS, and international collaborators from Canada, France, and Australia.

The Norwegian Environment Agency will act as project advisor to ensure good communication with regulatory authorities both in the planning of the project and for dissemination of project results.

In COPE, we aim to address this knowledge gap in a comprehensive cross-disciplinary research initiative. We will combine empirical data, time-trends, and statistical methods with mechanistic and novel modelling techniques. To enable development and evaluation of this cross-disciplinary approach, we will focus on data-rich ecosystems and species, including seabirds and polar bears. These animals are vulnerable to contaminants and climate change and can serve as indicator species for changes in ecosystem health.

At the core of COPE is the Nested Exposure Model (NEM). NEM is a unique spatially and temporally resolved integrated multimedia model for environmental fate and bioaccumulation of organic contaminants which is currently under development at NILU. The model is developed to increase our understanding of the complete link between emissions of contaminants on a global scale and resultant contaminant exposure in Arctic ecosystems and species.

In COPE, we will further develop and explore NEM to investigate contaminant transport to and within Arctic environment and food webs, and how this transport is influenced by climate change. Key questions include: Where and when is contaminant exposure expected to be the highest in the context of a changing climate? And is climate change or trends in contaminant emissions more decisive in controlling contaminant exposure in the past, present and the future?

We believe that the combination of the NEM model, the Fram Centre expertise and vast amount of empirical data, and complementary modelling tools at the Norwegian Polar Institute, will be a powerful approach to increase our understanding of the complex interactions between contaminants and climate change in Arctic ecosystems. Such knowledge is vital to support scientifically sound management strategies to ensure the future health of Arctic ecosystems. ■

COPE is a story of what the Fram Centre collaboration is all about: the necessity of collaboration across institutions and disciplines in order to answer complex environmental questions in the Arctic.

One important aim of the flagship “Hazardous substances” is that the yearly incentive funding from the Ministry of Climate and Environment, in addition to the unique collaboration opportunities and platform in the Fram Centre, should give momentum and result in new externally funded projects of high scientific quality and relevance for policy makers.

Both as head of the flagship and as research director for NILU in Tromsø, I am privileged to say COPE is a perfect example of this, and a result the efforts of dedicated and hardworking scientists – a true child of the Hazardous substances flagship.

—Eldbjørg Heimstad, NILU





*Photo: Jørn Berger Nyvoll / UiT The Arctic University of Norway*



*A harp seal.*

*Photo: Jo Jorem Aarseth / UiT The Arctic University of Norway*

Trude Haugseth Moe // UiT The Arctic University of Norway

# Centre at UiT continues to solve international Law of the Sea dilemmas

## SCIENCE AND SOCIETY

The KG Jebsen Centre for the Law of the Sea has been renamed the Norwegian Centre for the Law of the Sea (NCLoS). With 71% of the earth's surface covered by oceans, and with global warming changing the marine environment, knowledge on the Law of the Sea is in great demand.

“**T**HE LAW OF THE SEA, will continue to be very relevant in the foreseeable future,” says Tore Henriksen, professor and the leader of NCLoS. “Seventy-one percent of the earth's surface is covered by oceans, and with climate change, new issues that need to be resolved arise continuously, for example concerning access to and use of the ocean and its resources.”

The Centre was renamed in September 2019, when the six-year funding period from Stiftelsen KG Jebsen ended. NCLoS is part of the Faculty of Law at UiT The Arctic University of Norway, in Tromsø.

“We will continue at the same speed and scale as before,” affirms Professor Tore Henriksen.

The Centre currently has 32 employees of nine different nationalities. It is the world's largest Law of the Sea research centre and is increasingly receiving international acknowledgement and attention.

“Researchers from all over the world contact us. More and more want to cooperate, come here for research stints, apply for jobs with us, or invite us to hold presentations at conferences,” says Henriksen.



The employees at NCLOS – an international team.  
Photo: NCLOS / UiT The Arctic University of Norway

### CLARIFYING ECOSYSTEM RIGHTS AND PROTECTION

Major parts of the oceans are located outside national jurisdiction, and hence there is a need to find solutions and make agreements.

What happens, for instance, when fish that previously lived within a state's maritime borders find new areas to live due to increasing temperatures, and suddenly are in waters outside the jurisdiction of any state. Who has the right to fish?

“As the effects of climate change are already evident, there is a strong need to protect areas and ecosystems in the sea - like the coral reefs - so that they can survive. Thus, we need to have regulations in place,” explains Henriksen.

He himself could not have wished for any better workplace.

“The Norwegian Centre for the Law of the Sea is an amazing place to work, with exciting research tasks in a positive and inspiring international work environment,” the leader of the Centre concludes happily.

### KNOWN WORLDWIDE

Dr Anne Husebekk, rector of UiT The Arctic University of Norway, is also pleased to keep the Law of the Sea Centre at the University.

“The Centre for the Law of the Sea is a major and important initiative, funded in collaboration with the foundation Stiftelsen KG Jebsen in Bergen. This external funding has given the Centre an opportunity to employ exciting researchers, educate many PhD candidates and postdocs, and establish extensive international collaboration. The Centre is known worldwide. With time, the Centre will hopefully also receive funding from new external actors,” says Anne Husebekk. ■



Gravneset in northwestern Spitsbergen.

*Photo: Jørn Berger Nyvoll / UiT The Arctic University of Norway*

#### **THE NORWEGIAN CENTRE FOR THE LAW OF THE SEA IN NUMBERS:**

- Started 1 September 2013 as KG Jebsen Centre for the Law of the Sea
- Employees: 23, of 9 different nationalities
- Funding: 36 million NOK from the KG Jebsen Foundation. Currently funded by UiT The Arctic University of Norway / The Faculty of Law at UiT
- PhDs: eight so far, nine ongoing PhD projects
- Publications as of 31 September 2019: more than 160 articles, around 125 chapters in anthologies, 9 monographs (8 forthcoming), and 5 anthologies (6 forthcoming)
- Conferences, workshops, outreach: Nearly 50 conferences/workshops, two international summer schools for PhDs, media presence, dissemination activities to the public at large, and around 50 blog posts on the JCLOS blog.

Eva Fuglei // Norwegian Polar Institute

Arnaud Tarroux // Norwegian Institute for Nature Research

# Fox on the run – crossing the Arctic from Svalbard to Canada

## RESEARCH NOTES

An Arctic fox reached Ellesmere Island on 10 June 2018, just 76 days after leaving Spitsbergen. Her journey, one of the longest and fastest ever recorded in Arctic foxes, traversed 3605 km of sea ice, glaciers, and polar deserts, and took her to an ecosystem quite unlike the one where she was born.

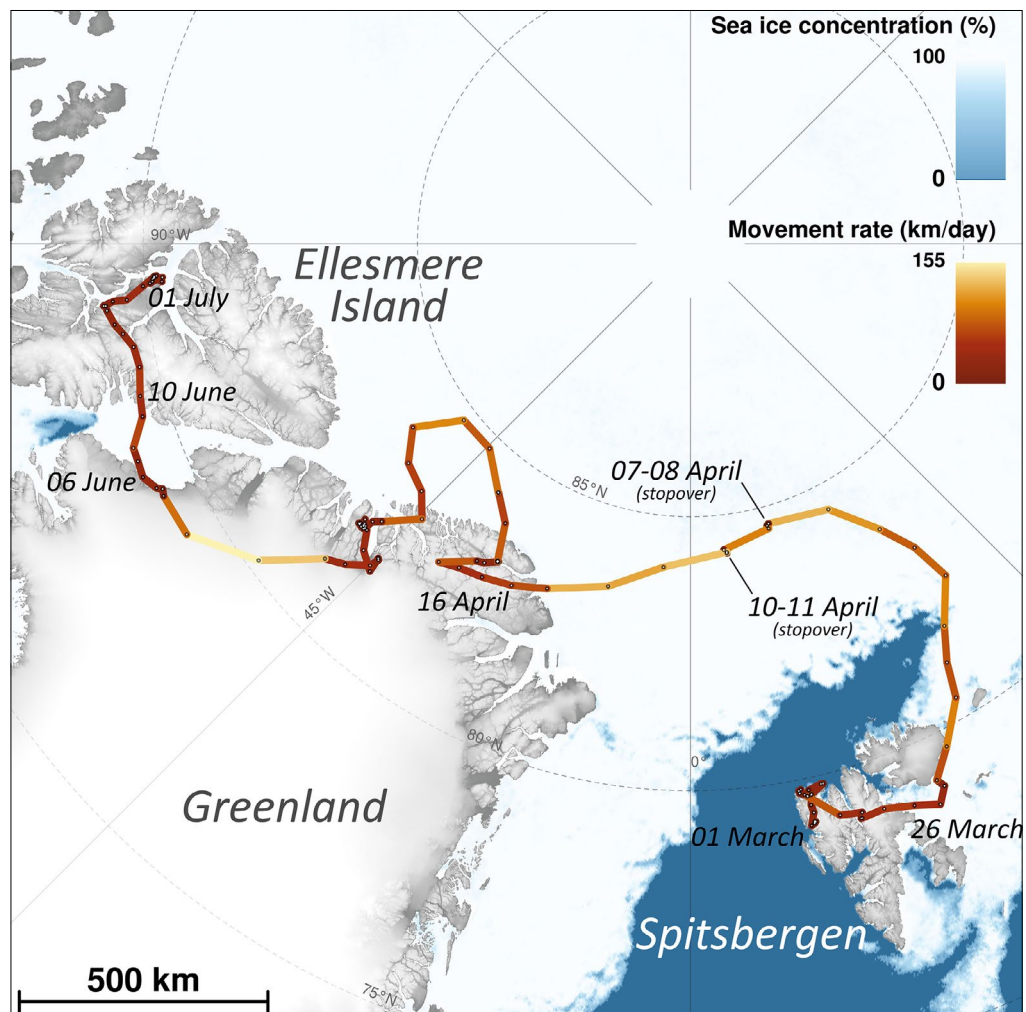
**T**HE ARCTIC FOX is the terrestrial mammal species with the widest distribution in the Arctic. This is due both to the fox's exceptional ability to live in some of the most hostile environments on Earth and to its capacity for long-distance movements. The extraordinary mobility of the Arctic fox was noted by the Norwegian polar hero Fridtjof Nansen in 1885, when he found fox tracks close to the North Pole. In modern times, telemetry has made it possible to record in detail how individual foxes move and use habitat within their normal home ranges, as well as when they wander to find new homes. In a project financed since 2012 by Fram Centre's Climate-ecological Observatory for Arctic Tundra (COAT) and the ICE program of the Norwegian Polar Institute, we have equipped

more than 60 Arctic foxes on Spitsbergen with satellite collars to study their spatial ecology. We are particularly interested in how they use land and sea ice in Svalbard, which is changing rapidly due to climate warming. While several of the foxes we have been monitoring ventured onto the sea ice, only one ended up outside Svalbard.

### PLACE OF ORIGIN

The Arctic fox in question was captured 29 July 2017 near the terminus of the glacier *Fjortende Juli-breen* in Krossfjorden, Western Spitsbergen. It was a young female, born the same summer probably in the same area and she was of the blue colour morph. Arctic foxes come in two colour types





Map of the long walk (from Fuglei and Tarrow, *Polar Research* 2019, doi.org/10.33265/polar.v38.3512)

(morphs), blue and white. The blue colour occurs most frequently in coastal areas without sea ice, such as in Iceland. In Svalbard, blue foxes make up approximately 7% of the population. Before the fox was released, she was outfitted with a satellite collar that made it possible for us to track her position every day. Little did we know she would undertake an epic journey, providing us with detailed evidence about how such long-ranging dispersal occurs.

The Arctic fox stayed put for seven months. In early March 2018 she started to explore northern Spitsbergen, moving across land and along ice-free shores until she met with sea ice for the first time on 26 March 2018.

#### TRAVELLING ON SEA ICE

After stepping out onto the sea ice she headed north and later west towards northern Greenland. While on the sea ice she moved with an average speed of approximately 46 km/day. On two occasions, she had short stopovers (7-8 April and 10-11 April), which may indicate that she had encountered physical barriers on the sea ice or bad weather - or food. The pack ice north of Svalbard is a dynamic environment characterised by frequent formation of leads: stretches of open water which appear in the ice, then close again. Leads can be biological hot spots for amphipods, seabirds and marine mammals, and may thus have offered the travelling fox a much-needed meal.

Conversely, leads can be obstacles - cracks several hundred metres wide, opening and refreezing over the course of a few days. Blizzards or other adverse weather conditions may also have forced the fox to find shelter until conditions improved.

After 21 days and 1512 km on the sea ice, the fox set foot on land again in northern Greenland on 16 April 2018. But she did not stop to rest. Her travel continued westwards over Greenland's massive ice sheet. This is where she reached the highest speed of her entire journey. In a single day, she covered 155 kilometres, the longest daily distance ever recorded for Arctic foxes.

#### TO A CANADIAN AREA NAMED BY NORWEGIANS

After having crossed the northern tip of Greenland, the Arctic fox returned to the sea ice again at Kane Basin on 6 June 2018. Four days later she set foot on Ellesmere Island, Nunavut, Canada, 76 days and 3512 km after leaving Spitsbergen. The fox continued westward to the Fosheim Peninsula, which she reached on 1 July 2018. This peninsula was named by the Norwegian Polar explorer Otto Sverdrup, leader of the second *Fram* expedition in 1898-1902. In 1899 they explored this area and named the peninsula after Ivar Fosheim, a



The Arctic fox is released after being tagged with a satellite collar by Tommy Sandal and Anna Marie Sandal Strømseng. Photo: Elise Strømseng

The most frequent question we got from the media was: "Does the fox have a name?"

#### A FOX NAMED ANNA

The publication of the first detailed observation of a fox dispersing from Europe to America sparked a lot of attention in media around the world. One of the most common questions from journalists was whether the young female fox had been given a name. The answer was negative until seven-year-old Anna Marie Sandal Strømseng was tasked with finding an appropriate name.

Being the daughter of trapper Tommy Sandal and Elise Strømseng, Anna Marie has spent a lot of time at the trapping station on Akseløya in Van Mijenfjorden, Svalbard. In fact, she helped capture and tag the Arctic fox that walked to Canada.

Anna Marie named the fox Anna in September 2019. How does she motivate choosing that name? In part, she named it after herself, a young trapper girl. In part, she named it after another trapping woman: Anna Oxaas, wife of the legendary trapper Arthur Oxaas.



One blue fox and one white fox feeding on a polar bear kill on the sea ice. *Photo: KL Laidre*



Anna Marie on field work. *Photo: Elise Strømseng*

Norwegian from Vestre Slidre in Valdres, who joined the expedition as a jack-of-all-trades. The Arctic fox stayed on Fosheim Peninsula until the satellite collar stopped transmitting on 6 February 2019, six months later.

#### NATAL DISPERSAL IN ARCTIC GLOBETROTTERS

It is quite normal that young animals move away from where they were born to settle in a new area where they may stay for the rest of their lives. This strategy, termed *natal dispersal*, is a way to find a territory that provides better possibilities for a successful life. Natal dispersal can be either a fixed, innate behaviour to avoid inbreeding, or conditionally induced by local competition for food, mates, or den sites. Which of these potential drivers of natal dispersal caused the young blue female to leave Spitsbergen is unknown. What is certain, however, is that it gave us a unique insight into how far and how fast such dispersal can be in Arctic foxes, and highlighted how important polar sea ice is in connecting the continents for these Arctic globetrotters. ■

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#### FURTHER READING:

Fuglei E, Tarroux A (2019) Arctic fox dispersal from Svalbard to Canada: one female's long run across sea ice. *Polar Research* 38: <https://polarresearch.net/index.php/polar/article/view/3512>

The Guardian, 2 July 2019. The story about an arctic fox that dispersed from Svalbard to Canada. <https://www.theguardian.com/world/2019/jul/02/fantastic-arctic-fox-animal-walks-3500km-from-norway-to-canada>.

<https://www.coat.no/Hjem/Nyhetsartikkel/ArticleId/4803/Vandringen-til-en-COAT-instrumentert-fjellrev-p-229-Svalbard-gikk-viralt> (In Norwegian)

En ekte Svalbardiansk fangstjente. *Svalbardposten*, nr. 34, 12. September 2019. <https://svalbardposten.no/pageflow-reader/view.php?avis=403#page=12> (In Norwegian)

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Eva Leu // Akvaplan-niva

# The melting Arctic: how algal blooms change in rapidly warming seas

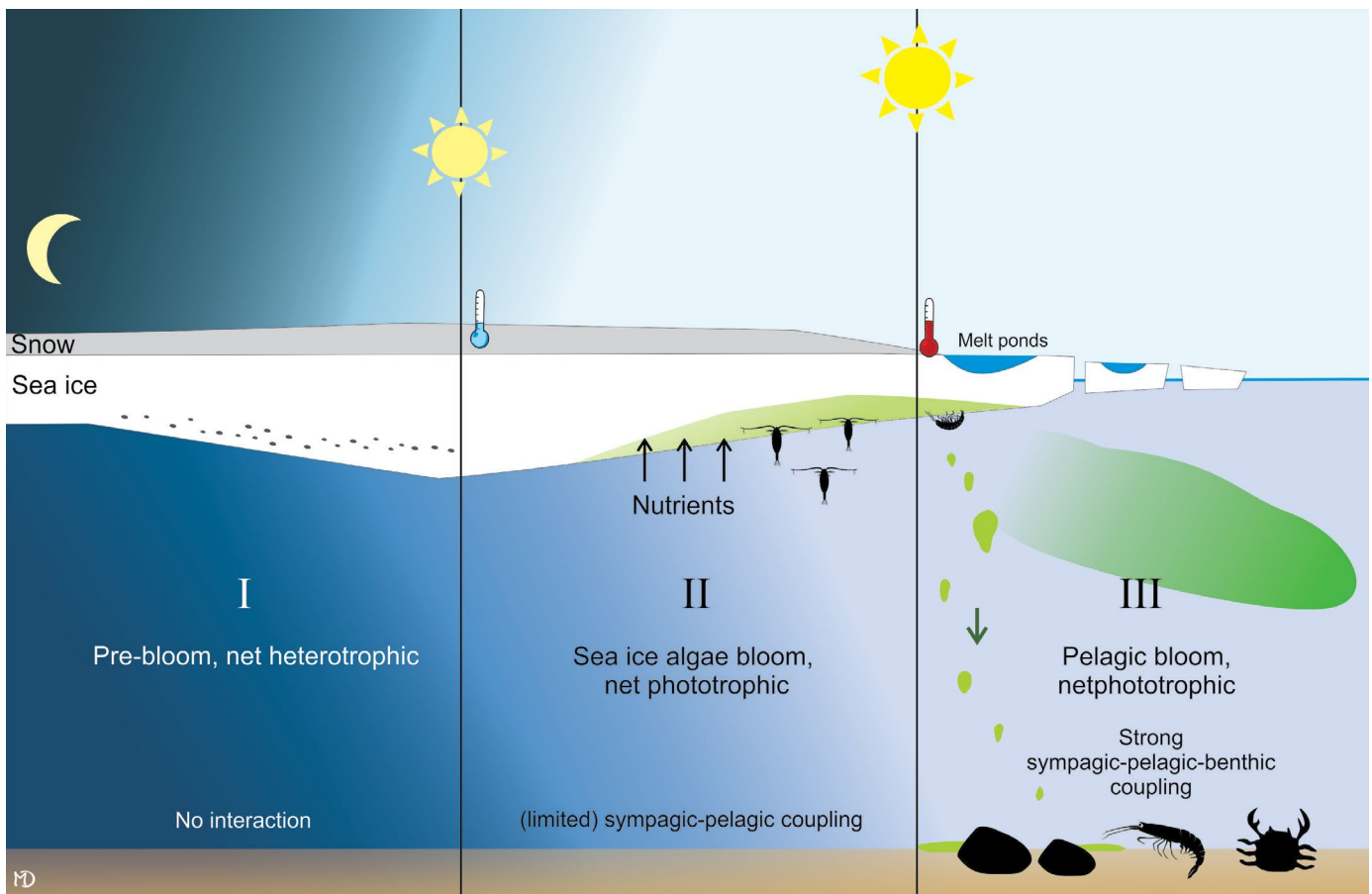
## RESEARCH NOTES

Arctic environments are changing rapidly. Clearly this poses challenges to ecosystems, but we do not yet understand the consequences in their full complexity. However, we know that the first response to sea ice decline, ocean acidification, and warmer waters happens at the level of unicellular algae.

**A**LGAE ARE PHOTOSYNTHETIC ORGANISMS that use sunlight to build up organic material from CO<sub>2</sub> and water. By doing so they form the basis for the marine food web. In the Arctic, these organisms face great challenges due to the complete lack of sunlight during the polar night. Even when the sun returns in spring, seasonal presence of sea ice restricts the amount of light that enters the water column. As a result, it is only during rather short periods of the year when there is both enough light and an adequate supply of nutrients that we see algal blooms. Many other organisms in the Arctic have tuned their life cycles towards this important food resource. Since algal growth is strongly controlled by environmental conditions, it is evident that climate-induced changes in the environment will affect algal blooms.

In ice-covered Arctic waters the first algal bloom upon the sun's return in spring occurs in the lowermost part of sea ice, close to the ice-water interface. In the ocean this marks the transition from winter to spring, usually occurring long before there are any signs of spring on land. Despite extreme conditions, the microscopic meltwater channels in this part of the ice offer a stable habitat for specialised unicellular algae. *Sea ice algae* are optimised to take advantage of very low light intensities, and their production is usually light limited through most of their growth season. Snow lying on top of the sea ice absorbs much more of the incoming sunlight than the ice itself, but once the snow starts melting, more light is transmitted, and other unicellular algae (*phytoplankton*) start blooming in the water underneath the ice.

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**FAABulous:** Future Arctic Algae Blooms – and their role in the context of climate change is a project funded by the Research Council of Norway (2015-2020), and led by Eva Leu, Akvaplan-niva. Five Norwegian partners (Akvaplan-niva, University Centre in Svalbard, UiT The Arctic University of Norway, Nord University, NIVA – Norwegian Institute for Water Research) collaborate with four international partners (Alfred-Wegener-Institute, Scottish Association of Marine Sciences, Institute of Oceanology-Polish Academy of Science, Max Planck Institute for Meteorology) working across disciplines such as sea ice optics, physical oceanography, algal ecophysiology, biochemistry, modelling.



Drilling ice cores to collect ice algae – one of the project's main field activities. *Photo: Eva Leu*



The FAABulous team on fieldwork in Van Mijenfjorden in April 2017. *Photo: Thomas Brown*

The timing of these two blooms is of great relevance for small crustaceans that feed on algae, including the copepod *Calanus glacialis*. These animals (and their sibling species) are central in making the biomass produced by algae available to animals further up in the food chain.

During the past four years, we have studied Arctic algal blooms in sea ice and water in the FAABulous project (see p 77) with many colleagues from the ARCTOS network (see article on p 36), and other national and international partners. We focused on two fjord systems in Svalbard with contrasting characteristics, where we studied the seasonal development of environmental conditions and algal blooms. Due to the remoteness of these fjords, we used autonomously deployed instruments that provided continuous data, as well as numerous field campaigns for collecting samples. Kongsfjorden, a fjord at 79°N that has been largely ice-free for the past decade and is strongly influenced by warm Atlantic water from the West Spitsbergen Current, represented a laboratory for a future climate scenario. The other fjord, Van Mijenfjorden, located further south along the west coast of Spitsbergen, is much more isolated due to an island blocking most of its opening. Hence, it is usually still covered with sea ice up to 4-5 months every year.

During our continuous study from September 2015 to August 2016 we found that the phytoplankton bloom started earlier in the ice-covered system, but algae biomass accumulation was slower. The ice-free Kongsfjorden had higher nutrient levels over a longer period and therefore supported a longer bloom and higher overall biomass production. We observe different groups of algae during different phases of the bloom development, and not all of them are of equally high quality as food for grazers. When comparing the two fjords, we found a surprisingly high overlap of species. The most distinct difference was that the early-spring community under the sea ice in Van Mijenfjorden was dominated by pennate diatom species. These species are usually associated with sea ice and were not found in Kongsfjorden.

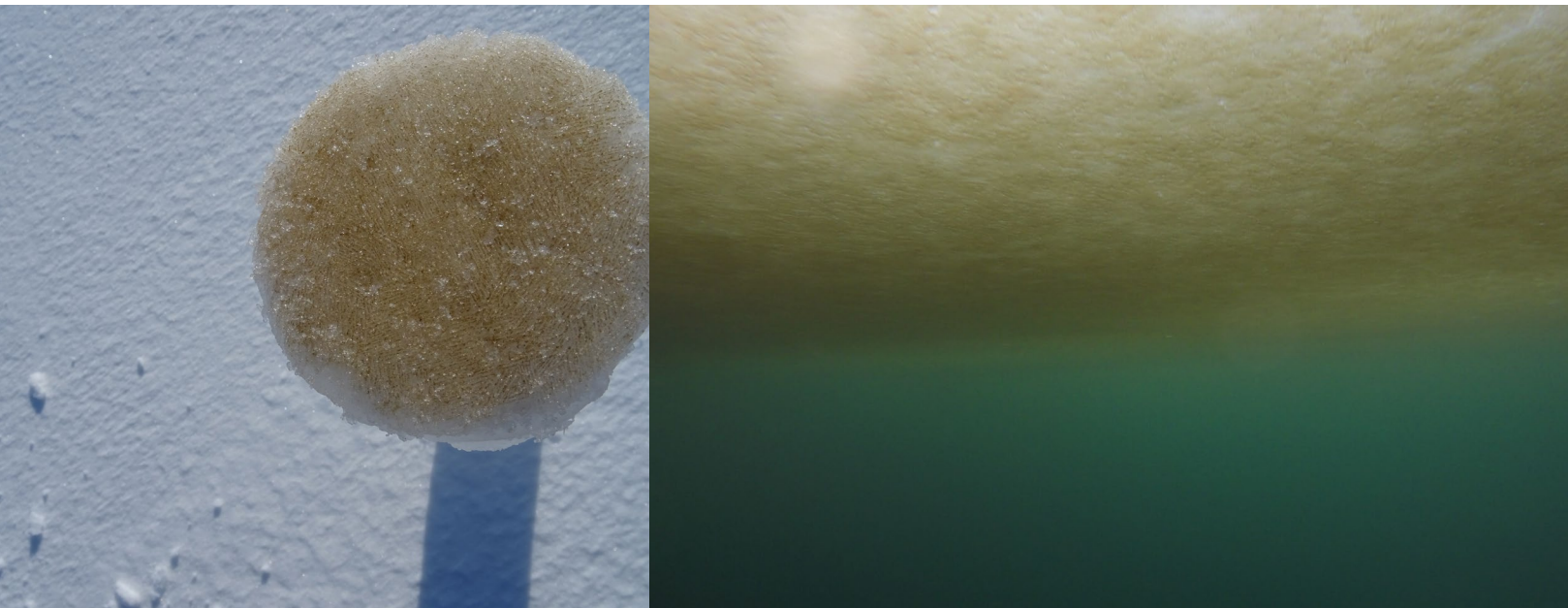


Jozef Wiktor and Eva Leu sample zooplankton from KV Svalbard (March 2017).

Photo: Sander Verbiest



Eva Leu and Ingrid Wiedmann deploying an underwater drone (Blueye) to take pictures of the underside of the sea ice. Photo: NTNU AUR-Lab / Blueye Robotics



Sea ice algae growing in the underside of an ice core.

Photo: Eva Leu

Sea ice algae form a brownish layer on the underside of the ice of Van Mijenfjorden in April 2017. The ongoing phytoplankton bloom colours the water green. Photo: NTNU AUR-Lab / Blueeye Robotics

When comparing the spring blooms in Kongsfjorden during three consecutive years (2016-2018), we found considerable differences in species composition between the years, which can be attributed to physical conditions. Huge interannual variability in the timing of phytoplankton spring bloom in Kongsfjorden has also been shown by measurements spanning a decade (2003-2013).

Apart from suitable environmental conditions, the initiation of a spring algal bloom is dependent on the presence of a viable seed population of algal cells that have survived the winter and are ready to start photosynthesis once they are re-exposed to sunlight. This overwintering of microalgae is only partly understood by scientists. We knew that very few algal cells are present in surface water during the polar night, and many of those few do not rely solely on photosynthesis. However, we knew nothing about their physiological state, or whether and how quickly they could resume active photosynthesis and growth.

To test this, we sampled natural phytoplankton communities in surface waters in January and December, and measured their physiological state in darkness, as well as after re-exposure to different light intensities in the laboratory. These experiments revealed that the algal cells had almost completely functional photosynthesis systems even after several months in very dim light. *In situ* incubation experiments in the fjord proved this level of light to be insufficient for net primary production. Upon re-exposure to light in the laboratory, however, the algae were capable of acclimating to a range of different light intensities within only 24 hours. This confirms that they would be able to start photosynthesis almost immediately when exposed to light.

Climate change is likely to alter the relative contributions of sea ice algae vs phytoplankton to primary production. Since these two blooms occur at different times and in different habitats, they are also primarily consumed by different groups of grazers. Changes in their relative importance





Through a microscope, the stunning diversity of phytoplankton becomes obvious. These specimens were sampled in Van Mijenfjorden during the spring bloom.

*Photo: Ane Cecilie Kvernvik*

therefore create potentially cascading effects through the food web. We performed experiments with natural communities and single-species cultures to study both groups' responses to an increase in light and also ocean acidification, which we expect to see in the future. Our results indicate that phytoplankton are better adapted to take advantage of higher light intensities and increase their production accordingly. Sea ice algae, on the other hand, appear much more vulnerable to high light and lower pH (ocean acidification), and seem destined to be the losers under future Arctic climate scenarios. Animals that rely on ice algae will therefore face challenges under future conditions.

■

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#### FURTHER READING:

Kvernvik AC, Hoppe CJM, Lawrenz E, Prasil O, Wiktor J, Greenacre M, Leu E (2018) Fast reactivation of photosynthesis in arctic phytoplankton during the polar night. *J Phycol* 54(4): 461-470. <https://doi.org/10.1111/jpy.12750>

Hegseth EN, Assmy P, Wiktor JM, Wiktor JM Jr, Kristiansen S, Leu E, Tverberg V, Gabrielsen TM, Cottier F (2019) Phytoplankton seasonal dynamics in Kongsfjorden, Svalbard and the adjacent shelf. In: *The Ecosystem of Kongsfjorden*, Hop H and Wiencke C (eds.), *Advances in Polar Ecology*, 173-228

Leu E, Mundy CJ, Campbell K, Gabrielsen T, Gosselin M, Juul-Pedersen T, Gradinger R (2015) Arctic spring awakening – steering principles behind the phenology of vernal ice algae blooms. *Prog Oceanogr* 139: 151-170

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Helge M Markusson // Fram Centre

# New technology opens up the Arctic for research

## SCIENCE AND SOCIETY

Automated platforms such as remotely operated vehicles and autonomous underwater vehicles – generally called ROVs and AUVs – allow scientists to reach totally new locations in the harsh environment of the Arctic.

**I**N SMEREENBURGFJORDEN, within view of the strait of Danskegattet, a small boat bobs up and down in the water. The surroundings are spectacular, but Martin Ludvigsen, professor of underwater technology, has his eyes glued to his mobile phone. Ludvigsen is using a little robot called Blueye. This is a new part of the everyday life of Arctic scientists. They can now use underwater drones instead of having to undertake the complicated diving operations as they did in the past.

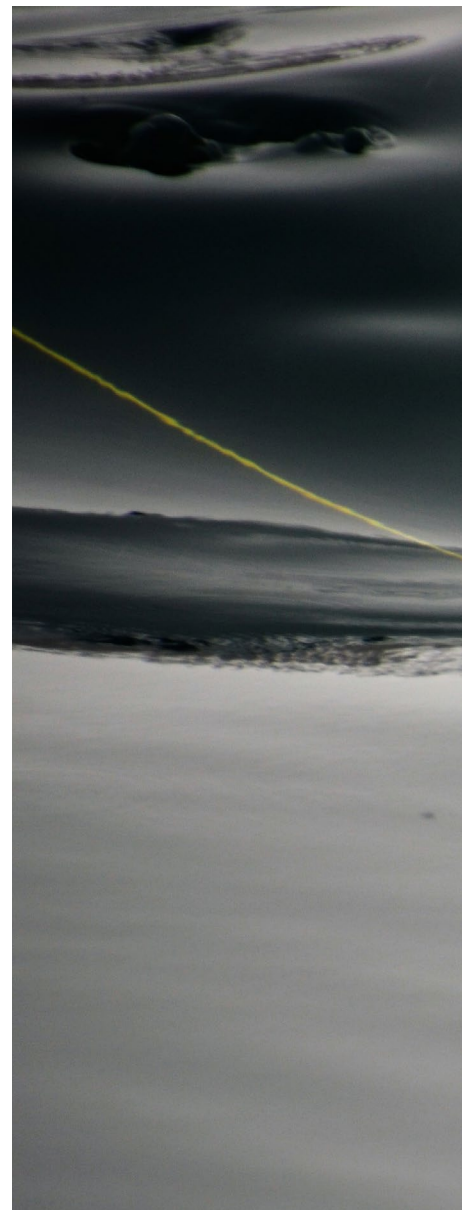
Together with students at the Norwegian University of Science and Technology, Martin Ludvigsen and Erik Dyrkoren developed the first prototype of Blueye in 2014. In 2015, the ROV was put into commercial production.

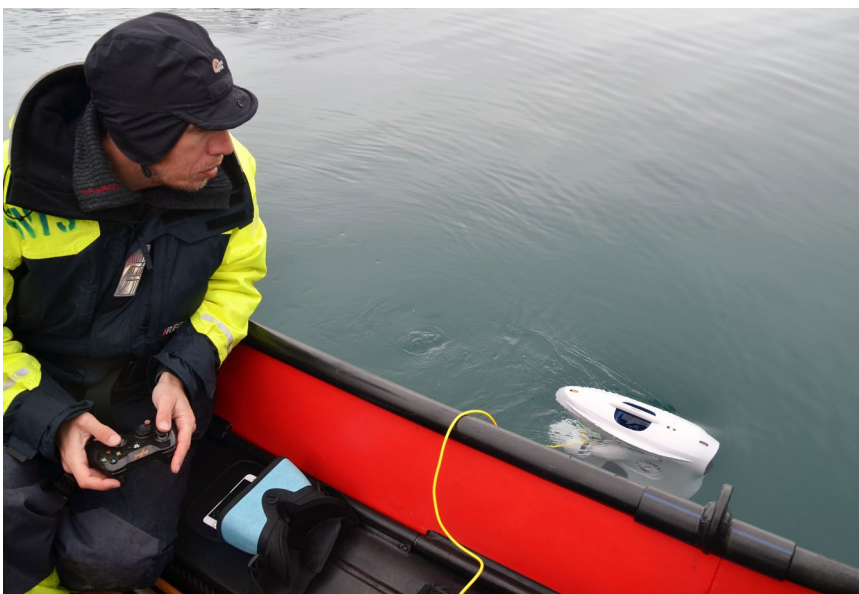
Today, the company that produces Blueye employs over 20 people with expertise in diverse fields: software, robotics, mechanical and industrial design, underwater technology, graphic design and business development. All these experts have been busy - and so have the drones. They are now used extensively.

## ENORMOUS POTENTIAL

Underwater robots can take samples and perform investigations in areas and at times of the year that are otherwise difficult to access.

“This will provide absolutely necessary insight into the ecosystems, which in turn have strong





Martin Ludvigsen, professor at the Norwegian University of Science and Technology, steers the Blueeye robot from the surface.  
Photos: Helge M Markussen / Fram Centre



Marine biologist Øyvind Ødegård from the Norwegian University of Science and Technology (left), pilot Stefan Eilertsen and Martin Ludvigsen deploying an ROV in northwestern Spitsbergen. Photo: Helge M Markusson / Fram Centre

### THE OUTREACH CRUISE

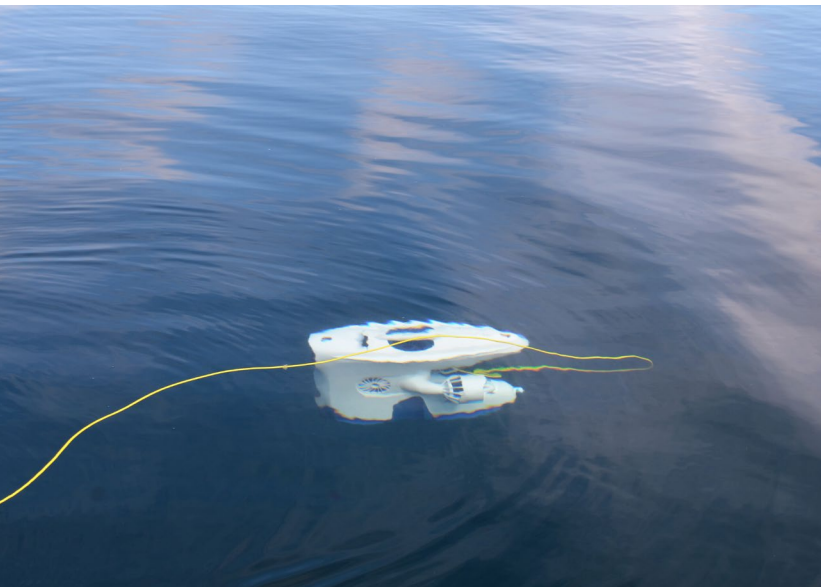
An Outreach Cruise is not a normal research expedition, but more of a floating seminar, where scientists, environmental managers, and trade and industry representatives exchange experiences and establish contacts.

The Outreach Cruise that took place at the end of June 2019 was a collaboration between UiT The Arctic University of Norway, the University Centre in Svalbard, and the Norwegian University of Science and Technology. An important topic

was how new technology can provide better knowledge about the Arctic.

The research vessel *Helmer Hanssen* was used as a base and carried three underwater drones from Blueye Robotics, as well as a Remus AUV developed by Kongsberg Gruppen.

An AUV is a type of submersible craft that can be remotely operated without cables. An ROV is usually controlled via cables.



Deploying equipment near the ice edge north of Svalbard at almost 80°N. Photos: Helge M Markusson / Fram Centre

indirect significance for any harvestable resources in the future,” says Jørgen Berge, professor at UiT The Arctic University of Norway.

At the same time, use of robots makes research more efficient and safer.

“From a marine biologist’s point of view, the technology has enormous potential to increase our understanding of Arctic marine systems,” says Berge.

#### **SMALLER FOOTPRINT**

With currently available technology, researchers still need to use large boats in order to deploy the drones, but this may change.

“In the not-too-distant future, there will probably be many automated platforms that can be deployed, docked, and charged automatically,” says Berge.

That will make access easier and - not least - reduce the environmental footprint.

“The data you get will be more authentic. You don’t have to be physically present and you aren’t dependent on light. Light itself is a source of pollution,” says Berge.

The polar night is an example of a season when it is difficult to do research. In fact, it is only during the last decade that researchers have begun to understand the significance of the four-month period of darkness in Svalbard.

“If you’d asked a marine biologist ten years ago what happens during the polar night, she would have said it’s a time of year when no production or activity takes place, and that the dark season has little ecological significance,” says Berge.

Now they know better. The polar night is an important period for many organisms, and several of these discoveries have been made because the Arctic has become more accessible.

#### **LARGER AREAS**

Berge has taken part in many Svalbard expeditions, for example to monitor hard-bottom fauna. Since the 1980s, UiT has sent out divers once a year photograph approximately two square metres of the seabed.

“Instead of two square metres, an AUV can cover 20 or maybe even 200 square metres several times a year. This means the data-set will be much larger and can provide answers to questions about seasonal changes,” says Berge. ■

Charmain D Hamilton, Jade Vacquié-Garcia, Kit M Kovacs,  
Jack Kohler and Christian Lydersen // Norwegian Polar Institute  
Rolf A Ims // UiT The Arctic University of Norway

# Contrasting responses to climate change by two Arctic marine mammal species

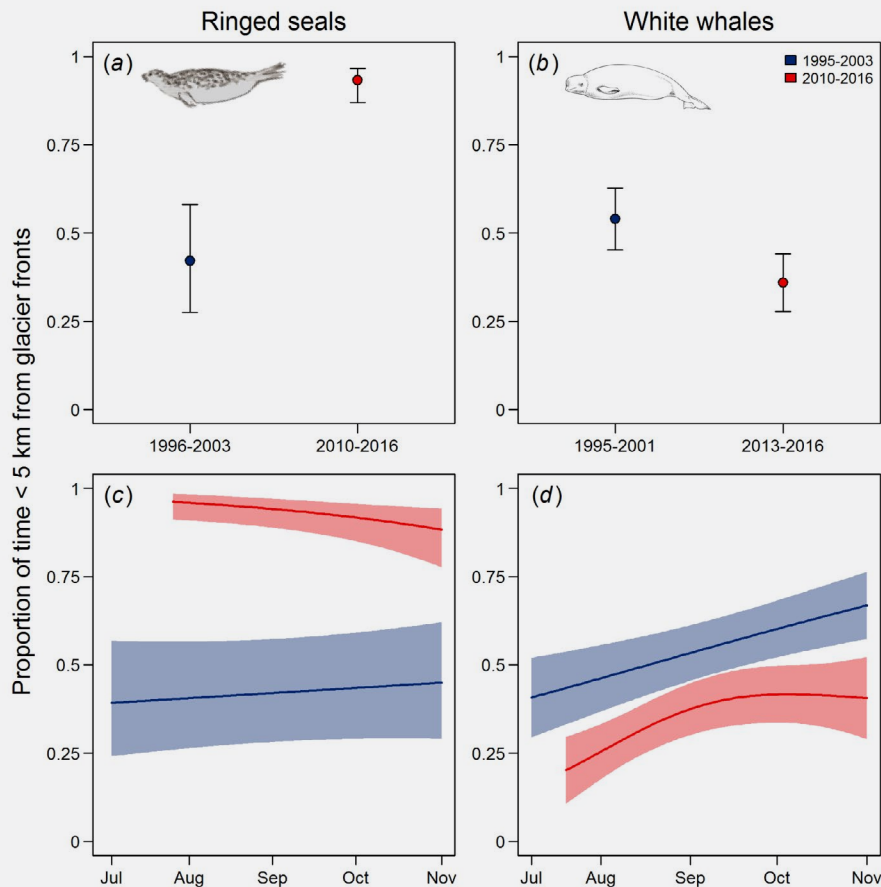
## RESEARCH NOTES

Ringed seals and white whales live year-round in Svalbard's coastal waters. One of these species seems to be adapting to use Atlantic water (and associated fish species), which are both increasing in this region. The other continues to rely on Arctic habitats and fish species that are in decline.

**T**HE ENVIRONMENT AROUND SVALBARD is in a state of rapid change. The sea-ice extent is declining rapidly, especially in west coast fjords where only limited amounts of land-fast ice (i.e. ice connected to shorelines) now form in the winter. Atlantic Water is increasingly intruding into Svalbard's coastal areas, bringing with it Atlantic fish species such as capelin and Atlantic herring. Glaciers are also shrinking and the number of tidewater glaciers (glaciers that terminate in the ocean) has decreased over the last few decades.

Ringed seals and white whales are endemic Arctic marine mammals that are found in coastal areas of Svalbard throughout the year.

They predominantly eat ice-associated prey and have historically spent a lot of their time near tide-water glaciers. Due to their long lifespans and the rapid pace of climate change, they will not be able to adapt genetically to the drastic changes that are taking place in their habitats. If these species are to thrive in the Arctic of the future, they will need to adjust to a new ecological reality by changing their behaviour and diet (i.e. by exhibiting behavioural plasticity). However, their capacity to respond to new conditions through behavioural adjustments is currently unknown: will they begin to use the new type of environment and prey types or will they seek out Arctic refugial areas where their "traditional" prey remain?



The proportion of time spent near tidewater glaciers by ringed seals and white whales before (1995-2003; blue) and after (2010-2016; pink) a major change in environmental conditions.

Figure from Hamilton et al 2019, *Biology Letters* 15: 20180834.

## OUR NATURAL EXPERIMENT

To address this question, we used data from biotelemetry tags. These tags are attached to individuals from each species and send information via satellite systems about where animals are, as well as aspects of their behaviour (e.g. dive depths, dive durations, time spent resting on sea ice). We compared data from animals tagged when conditions were historically “normal” (1995-2003) and data from animals tagged after the environmental changes began to occur in earnest (2010-2016) in areas that are influenced by Atlantic Water (west coast of Spitsbergen and Storfjorden). We analysed how much time each species spent in areas near

tidewater glaciers in each time period, and if their use of different glacier fronts depended on the length of the glacier’s calving front, or the water depth at these sites. We focused on changes during the summer and autumn, as these seasons are important foraging periods for both species.

## ATLANTIFICATION: IMPACT ON TOP PREDATORS

We found that ringed seals and white whales had opposite responses to the large environmental changes that have occurred in Svalbard’s coastal regions. When conditions were historically “normal” (1995-2003), both species spent about half



Pod of white whales swimming in Svalbard.

*Photo: Andrew Lowther / Norwegian Polar Institute*

of their time in areas near tidewater glaciers and their diets were dominated by polar cod, an Arctic fish species that lives in cold water, often in cracks in sea ice when young and at various water depths depending on age. However, after the conditions had changed (2010-2016), ringed seals spent 93% of their time near tidewater glaciers, significantly more time than in the past, while white whales spent significantly less time (36%) near tidewater glaciers. One behaviour that had not changed was that both species preferentially foraged near the largest tidewater glaciers in the region. These glaciers generally have long calving fronts that lie adjacent to deep water.

The frontal areas of tidewater glaciers are important foraging areas for many marine mammal and seabird species in Svalbard. Due to meltwater discharge from the glacier and ocean circulation patterns within fjords, prey species are concentrated near tidewater glaciers. In addition, these areas serve as refugia, retaining Arctic water

masses and Arctic fish species, such as polar cod. Calved pieces of glacier ice also provide resting platforms for seals and various species of seabirds. Ringed seals are more tightly coupled to these areas now than in the past and have smaller home ranges (i.e. areas where an individual seal spends most of its time) than a few decades ago.

In contrast to ringed seals, white whales are not retracting into Arctic glacial refuge areas. They currently have larger home ranges than a few decades ago and are spending more time in the central areas of fjords, where they have been observed milling at the surface (i.e. indicative of foraging activity) in recent years. In these mid-fjord areas, they are presumably feeding on Atlantic fish species that are transported into the Arctic with the increased volume (and temperature) of Atlantic Water reaching high latitudes. Differences in the dietary flexibility between these two





Ringed seal resting on a calved piece of glacier ice in Svalbard. *Photo: Kit Kovacs and Christian Lydersen / Norwegian Polar Institute*

species likely underpin their differing responses to climate change. Research from other areas of the Arctic has found that white whales are more flexible in their dietary choices than ringed seals.

#### CONSEQUENCES FOR THE FUTURE

The behavioural and dietary flexibility exhibited by white whales bodes well for their chances of adjusting to the new environmental conditions in Svalbard. However, the ringed seals' continued reliance on shrinking Arctic habitats and declining Arctic prey is a serious concern. Species that lack the behavioural flexibility required to respond to changes occurring in their habitats are almost certain to decline as the climate continues to warm. This study highlights that Arctic marine mammals are being impacted differently by climate change. Monitoring and research on individual species is needed to support management and conservation efforts and help ensure the continued existence of top predator species in a time of rapid change. ■

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Sea lice on a salmon's tail.  
The louse to the right has an  
egg string. Photo: Karin  
Bloch-Hansen, Akvaplan-niva



Adult female lice on a salmon.  
The long strings contain eggs.  
Photo: Karin Bloch-Hansen,  
Akvaplan-niva

Gro H Refseth, Maj Arnberg and Luca Tassara // Akvaplan-niva  
Pernilla Carlsson // NIVA Norwegian Institute for Water Research

# Do delousing agents used in aquaculture solve a problem or create one?

## RESEARCH NOTES

A creature just a centimetre long causes major losses of farmed salmon and imposes significant costs on aquaculture. Moreover, this tiny creature poses a threat to salmon and char living in the wild, as well as other marine organisms. Why is that, and what can we do about it?

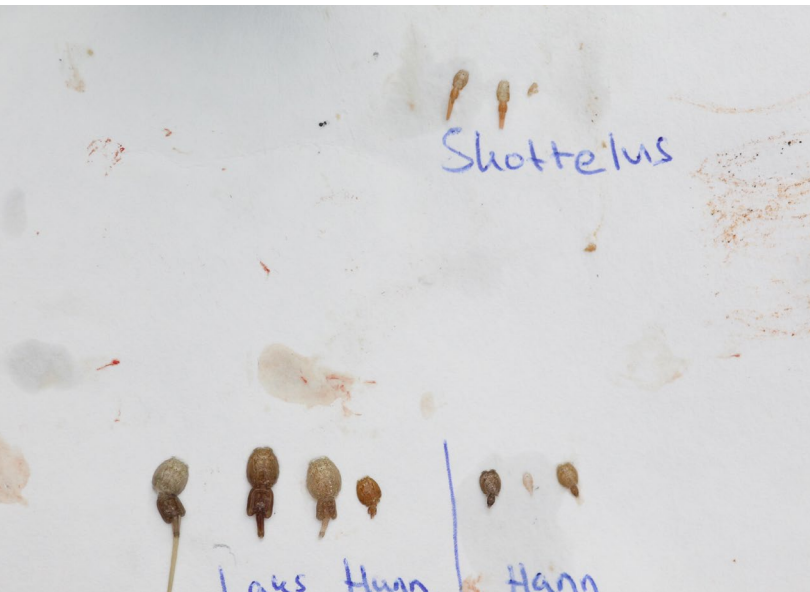
**S**EA LICE ARE SMALL ECTOPARASITES that eat through the skin and muscle tissue of their host fishes. Our study is focused on *Lepeophtheirus salmonis* and *Caligus elongatus*, two distinct species that share the English name “sea louse”. Both species parasitise salmonid fishes, but *C. elongatus* can also use other fishes as hosts. About 10% of wild salmon die each year due to sea louse infections, many of which originate from farmed salmon. Therefore, sea louse levels in salmon aquaculture need to be kept below a certain threshold to reduce infection of wild salmonids such as salmon and char. At the same time, any negative impact de-lousing chemicals have on the marine environment must be taken into account in the overall assessment.

Traditionally, the main method for delousing farmed salmon has been to use pharmaceuticals. However, the treatment agents have often been adopted from agriculture, where they were used

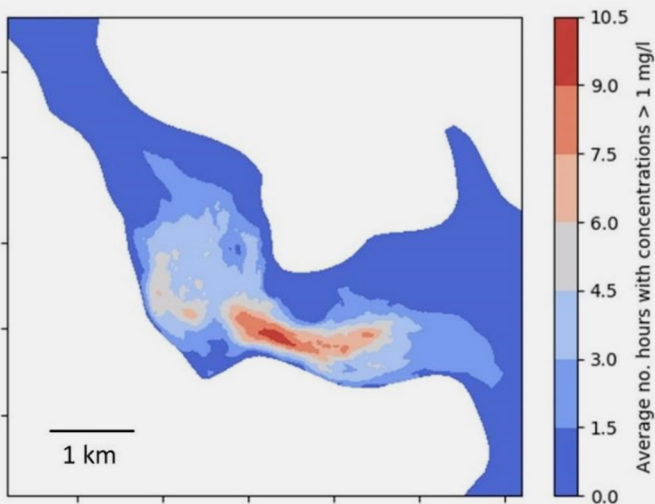
against other crustaceans, i.e. the same class of animals as sea lice. These treatment chemicals have proven effective against sea lice; but concerns have also been raised about possible effects on other marine crustaceans such as shrimps, krill, and crabs.

## ENVIRONMENTAL IMPACTS OF DELOUSING AGENTS

To combat sea lice, salmon can be treated with bath treatments, either directly in the fish cages or in well boats. The salmon can also be treated with chemicals added to the feed (in-feed treatments). A general principle for treatment with the different bath pharmaceuticals is that the fish can stand a higher dose over time than the sea lice can. However, the pharmaceuticals may harm fish that are exposed too long, so the bath treatment pharmaceuticals need to be removed quickly after treatment. The duration and strength of the bath



Sea lice change exoskeleton throughout their lives. This photo shows various developmental stages. Photo: Karin Bloch-Hansen, Akvaplan-niva



Modelled distribution of hydrogen peroxide showing how toxic concentrations may spread in the environment after a delousing event. Modelling with FVCOM by Ole Anders Nøst, Akvaplan-niva

treatments are determined by veterinarians. A bath treatment can be done inside the pens with a tarpaulin around, or in a well boat, in which case the fish are transported onboard, treated and released back into the pen afterwards. When treatment is done inside the pens, the treatment solution spreads when the tarpaulin is removed. This can be problematic if the pens are close to spawning fields or other sensitive marine life. When a well boat is used, the treatment water can be dumped in better suited areas.

The general mechanism by which feed-distributed pharmaceuticals combat lice is to inhibit formation of a new exoskeleton. Like all crustaceans, sea lice need to change their shells as they grow. In-feed treatment is provided as feed pellets to which pharmaceuticals are added. Hence, the fish are unlikely to be overexposed to the pharmaceutical, but unconsumed pellets (and faeces from treated fish) may sink and be consumed by other animals. Laboratory studies have shown that delousing chemicals used in the aquaculture industry cause lethal effects on marine species other than sea lice, and have also documented negative effects on different species at concentrations lower than those resulting from release of delousing agents into the environment after treatment.

One question that arises is why these pharmaceuticals are released into the sea rather than being taken ashore for destruction after a delousing treatment. The simple answer is that it would be costly, but to some extent the problem is lack of feasible technological solutions.

A number of toxicological tests done by Akvaplan-niva at the research facility in Kraknes on Kvaløya have examined various delousing chemicals and their effects on different marine species. To be able to understand the probability for the presence of toxic concentrations in the marine environment, oceanographic modelling of the spread of delousing chemicals in the water column and down to the sea floor were combined with results from these ecotoxicological experiments. This has provided some of the first assessments of the risks delousing chemicals pose to cold-water species and ecosystems.

In general, these studies show a risk of negative environmental effects when delousing agents are used. Harmful concentrations can spread several kilometres away from the discharge point. From this, scientists have concluded that crustaceans, and especially deep-water shrimp (*Pandalus borealis*), are vulnerable, as the shrimp die after short-term exposure to low concentrations. The bath treatment agent deltamethrin (Alphamax®) had the most severe effect: treatment concentrations diluted 1:330 were still lethal to the shrimps. An ongoing project funded by the Fram Centre flagship MIKON is investigating this further, conducting experiments with different deltamethrin concentrations and varying the exposure time as well, mimicking the real-life scenario during a delousing event in the ocean.

Results from this study are not published yet, but early experiments are in line with previous results. Deltamethrin is not the only bath treatment pharmaceutical used against lice. Hydrogen peroxide (Paramove®) has been used extensively since 2013. This chemical was first believed to degrade very quickly and have little or no impact on the environment, but recent modelling and ecotoxicological studies have revealed that biological communities can be damaged after the release of hydrogen peroxide. However, the risk was smaller when a well boat was used, than when the chemical was discharged directly from cages, because of more efficient dilution of the hydrogen peroxide. A “safe” concentration, i.e. one that does not have any unwanted effects on the marine environment, was estimated by modelling and experiments and set to around 11 000 times dilution of the concentration of hydrogen peroxide used in a delousing bath.

According to standardised international guidelines, risk-reducing measures should be implemented when there is a risk of negative environmental effects. A growing number of studies show that delousing agents have effects on non-target organisms and the ecosystem, and that they spread farther from the fish farms than first anticipated. Therefore, use of these chemicals is declining, not only to protect shrimps, cod larvae, and ecosystems, but also because of the risk that the sea lice are developing greater resistance. ■

These studies were financed by the Fram Centre’s MIKON flagship and FHF (Norwegian Seafood Research Fund).

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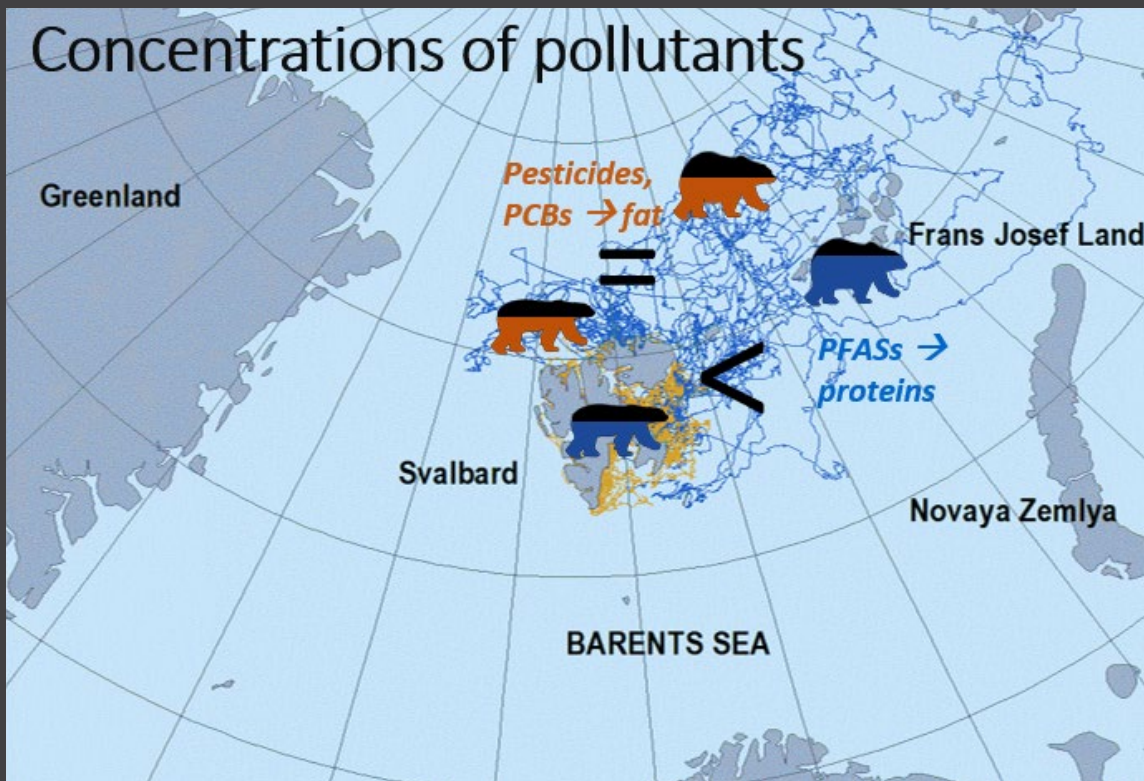
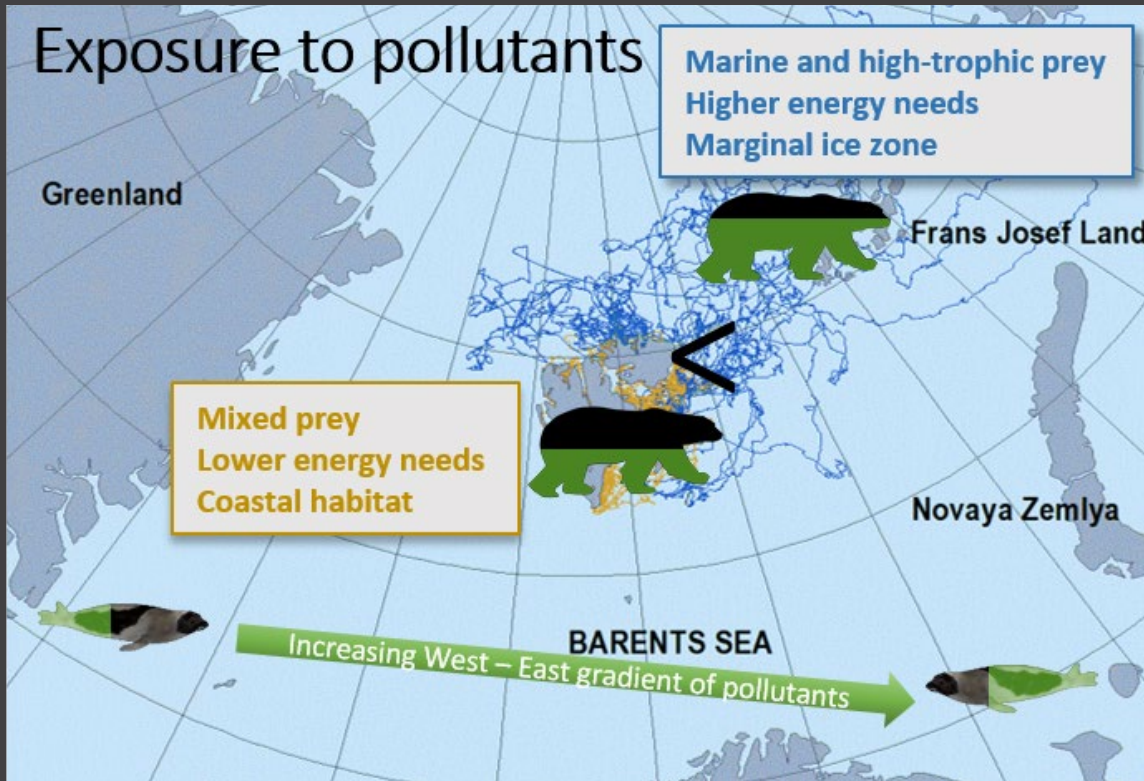
Pierre Blévin\*, Jon Aars, Magnus Andersen, Anna Lippold, Sabrina Tartu and Heli Routti // Norwegian Polar Institute  
Marie-Anne Blanchet // UiT The Arctic University of Norway  
Linda Hanssen and Dorte Herzke // NILU – Norwegian Institute for Air Research

# What drives pollutant exposure in Barents Sea polar bears?

## RESEARCH NOTES

Polar bears in the Barents Sea population use their environment two different ways. Bears that spend most of their time offshore are exposed to higher levels of pollutants than bears that stay along the coast due to differences in feeding habits, energy expenditure and geographical distribution.

\*Currently affiliated with Akvaplan-niva AS



Offshore polar bears in the Barents Sea population are exposed to higher levels of pollutants than coastal polar bears due to differences in feeding habits, energy expenditure and geographical distribution. Concentrations of pollutants that accumulate in fatty tissues are similar in fatter offshore and in thinner coastal bears. Tracks of offshore polar bears are in blue and tracks of coastal polar bears are in orange.

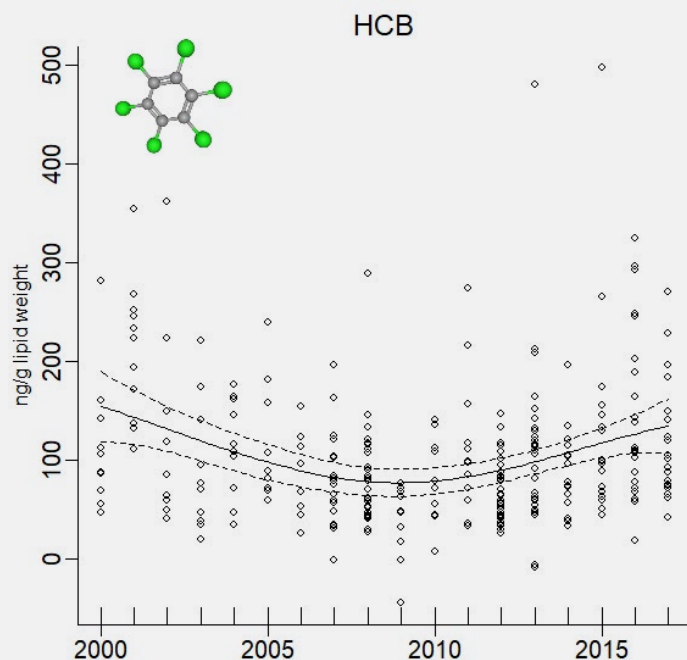


**P**ERSISTENT ORGANIC POLLUTANTS (POPs) are man-made chemicals. They have been used intensively for numerous agricultural, industrial, and commercial applications and it takes many decades for them to break down in the environment. Atmospheric and ocean currents, as well as river outflows, bring POPs to the Arctic, where they biomagnify in food webs and bioaccumulate in individual animals over a lifetime. Polar bears (*Ursus maritimus*) are top predators of the Arctic ecosystem and can live for up to 30 years. This means they are exposed to relatively high levels of pollutants over a long period of time, which may cause a wide range of adverse health effects. Polar bears from the Barents Sea have considerably higher concentrations of some pollutants than other subpopulations.

Arctic sea ice, which is the main habitat where polar bears travel, hunt and mate, is declining very fast in the Barents Sea. The loss of sea ice is

the greatest threat to polar bears. It is therefore crucial to understand how the combined impacts of habitat loss, pollutant exposure and reduced food availability might affect the bears.

Barents Sea polar bears have two distinct ways of using their environment to cope with seasonal variation of sea ice extent. “Offshore bears” undertake long annual migrations to follow the sea ice as it retreats into the north-eastern Barents Sea. “Coastal bears” stay close to the Svalbard archipelago in the western part of the Barents Sea year-round, using sea ice close to shore and glacier fronts as preferred hunting areas. Sea ice loss due to climate change means that the migration routes of offshore bears are getting longer. Around Svalbard, longer periods with reduced sea ice force coastal bears to feed more on land-based prey. Consequently, in the Barents Sea, offshore and coastal polar bears must cope with very different ecological challenges.



Hexachlorobenzene levels in Barents Sea polar bears from 2000 to 2017. After implementation of international regulations, the concentrations of several legacy POPs gradually decreased in Barents Sea polar bears. More recently, levels of some POPs have begun to increase again, possibly because they are being re-released from melting sea ice, glaciers and permafrost. Hexachlorobenzene is one such pollutant. This graph shows trends over time, adjusted for climate-related variation in the bears' body condition and feeding habits (adapted, with permission, from Lippold et al 2019, *Environmental science & technology*, 53(2), 984-995, © 2019 American Chemical Society).

Recent research by the Norwegian Polar Institute and collaborators from other Fram Centre institutes has provided knowledge about ecological drivers of pollutant exposure in Barents Sea polar bears. We have identified three important driving factors: what the bears eat, where they spend their time, and how much energy they use.

- Offshore polar bears are exposed to higher concentrations of pollutants than coastal bears because they feed primarily on marine prey high up in the food web (e.g. seals). Coastal bears rely on a mixed diet including land-based prey (e.g. seabird eggs, reindeer).
- Offshore polar bears are distributed further north and east than coastal polar bears, preferentially in the transition zone between open ocean and sea ice (the marginal ice zone). Farther north, the uptake of pollutants released from melting ice and snow during peak spring plankton blooms leads to high concentrations in the food web. Farther east, the bears' prey is more polluted, probably owing to proximity to pollutant emission sources and transport pathways.
- Offshore polar bears have higher energy expenditure because they spend more time reaching their foraging habitat and because they hunt for seals over larger areas. Coastal bears live in more restricted areas and feed opportunistically on whatever is available locally. Consequently, offshore bears need more energy, eat more food, and hence assimilate more pollutants than coastal bears.

Despite these differences in exposure, only one type of studied pollutants is currently higher in the blood plasma of offshore bears: perfluoroalkyl substances (PFASs). PFASs bind to proteins in blood and liver, whereas other POPs, such as polychlorinated biphenyls (PCBs) and chlorinated pesticides, are stored in fatty tissues. Concentrations of pollutants that accumulate in fatty tissues are similar in offshore and coastal bears. This is because offshore bears are fatter than coastal bears, and pollutants that bind to fat are more diluted in fat bears than in thin coastal bears.

The use and production of the so-called “legacy” POPs has long been banned or restricted by international regulations such as the Stockholm Convention. In response, Barents Sea polar bears' exposure to legacy POPs has generally decreased over the past 20 years. Nonetheless, levels of some compounds have been increasing during the last decade in Barents Sea polar bears. This can probably be attributed to re-emission of pollutants from melting sea ice, glaciers and permafrost. ■

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Akvaplan-niva Report 8926

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A female polar bear and her cub. Since she was observed in summer in Kongsfjorden, on the west coast of Spitsbergen, she is probably a coastal bear. *Photo: Pierre Blévin*

Alexey V Golikov and Rushan M Sabirov // Department of Zoology, Kazan Federal University, Kazan, Russia  
Martin E Blicher // Greenland Climate Research Center, Greenland Institute of Natural Resources, Nuuk, Greenland  
Filipe R Ceia and Jose C Xavier\* // Marine and Environmental Sciences Centre, Department of Life Sciences, University of Coimbra, Coimbra, Portugal  
Denis V Zakharov\*\* // Laboratory of Coastal Researches, Polar Branch of All-Russian Research Institute of Fisheries and Oceanography, Murmansk, Russia  
Olga L Zimina // Laboratory of Zoobenthos, Murmansk Marine Biological Institute, Murmansk, Russia  
Lis L Jørgensen // Institute of Marine Research, Tromsø, Norway

# Ecological role of the Arctic's most abundant cephalopod, *Gonatus fabricii*

## RESEARCH NOTES

Recent studies provide new insights into the ecology of the squid *Gonatus fabricii* in the Arctic, revealing its ecological role to be more important than previously believed, and substantially clarifying its distribution patterns, reproductive biology and trophic ecology.

**T**HE COMMON, WIDESPREAD SQUID SPECIES *Gonatus fabricii* (Cephalopoda), despite its English name (boreoatlantic armhook squid), has most of its range in the Arctic. It is the most abundant species among Arctic cephalopods, and its biomass reaches 8 million tonnes in the Nordic Seas. It is also the only squid amongst the 10 species of cephalopods that live permanently in the Arctic. It is therefore an important link in the polar ecosystem as both prey and predator. However,

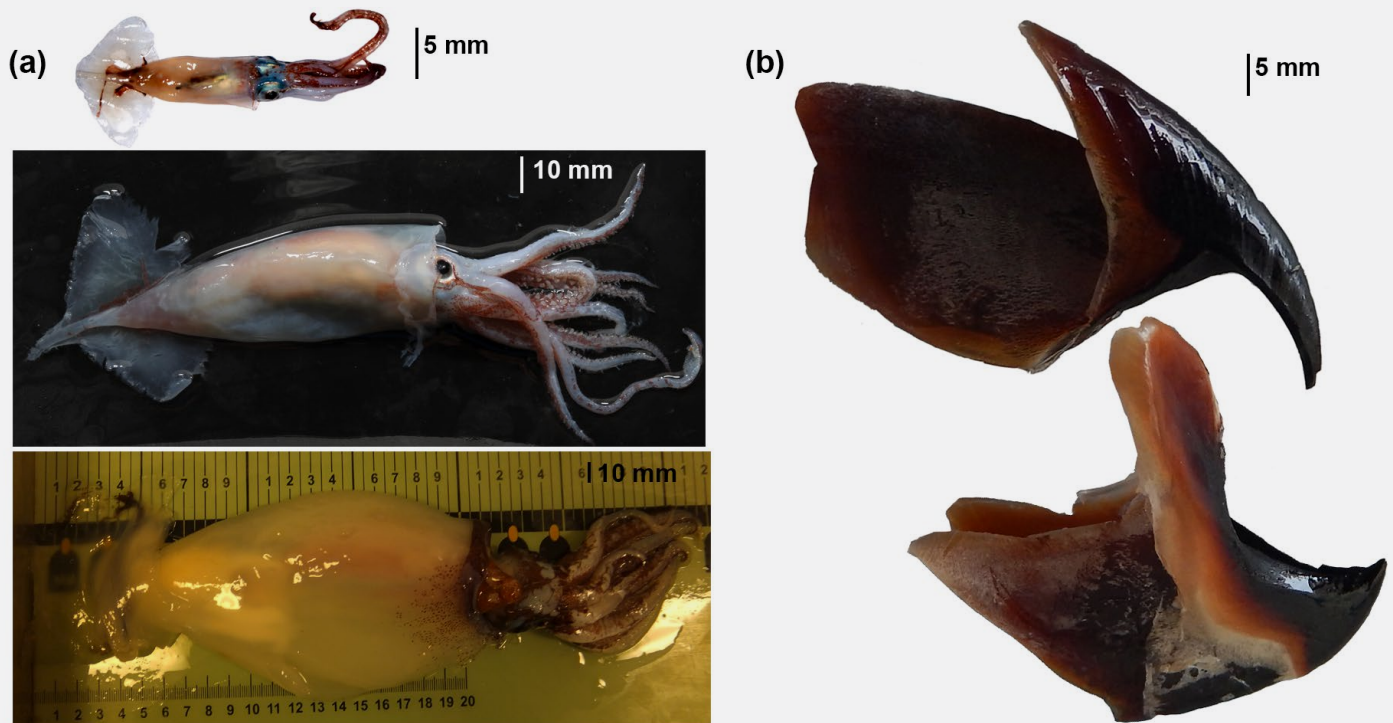
its trophic ecology, reproductive biology, and biomass distribution in the Barents Sea were mostly unknown until recently, when our studies filled those gaps. We also demonstrated that *G. fabricii* is much more important in the Arctic ecosystems than previously believed.

Despite the wide range of *G. fabricii*, our findings confirmed that this squid spawns within a geographically restricted area (as initially

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\* Also affiliated with British Antarctic Survey, Cambridge, UK

\*\* Also affiliated with Laboratory of Zoobenthos, Murmansk Marine Biological Institute, Murmansk, Russia

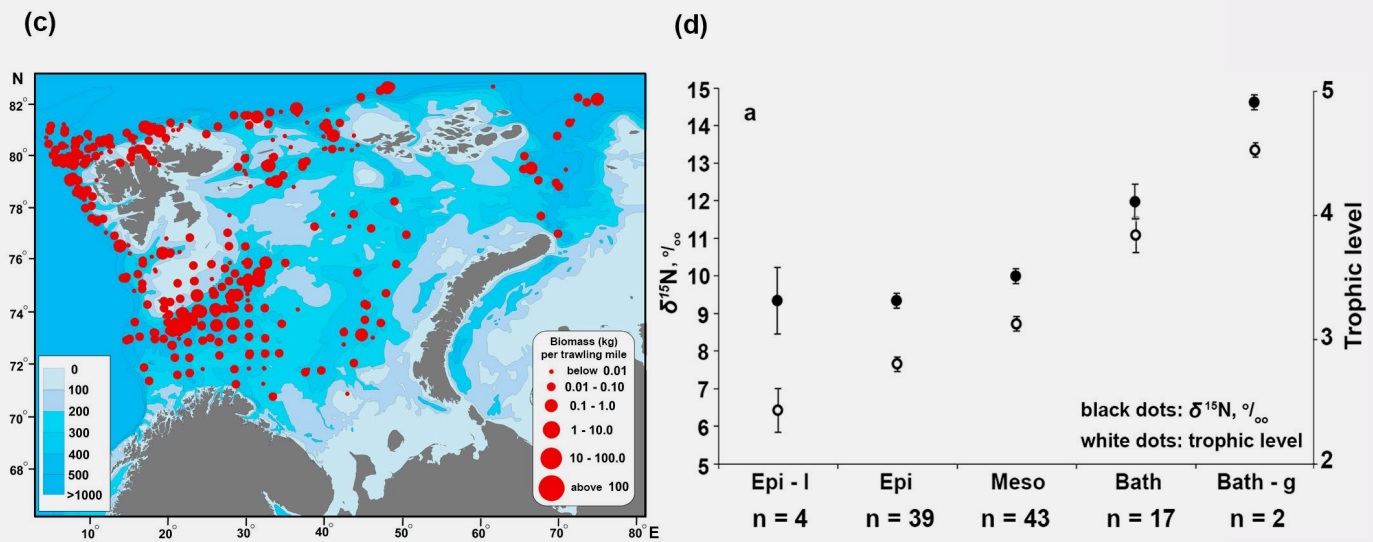


Panel a) *Gonatis fabricii* specimens at three different developmental stages. Top to bottom, surface-dwelling juvenile, mantle length 21 mm, from the Barents Sea (Photo: Pavel A Lubin), maturing male, mantle length 144 mm, from intermediate depth off West Greenland (Photo: Olga L Zimina) and bottom-dwelling, gelatinous, late-maturing female, mantle length 215 mm, from the Barents Sea. (Photo: Alexey V Golikov)

Panel b) Upper and lower beaks of a bottom-dwelling adult male *Gonatis fabricii*, mantle length 273 mm, from West Greenland. (Modified from Golikov et al 2018)

hypothesised by Herman Bjørke in 1995). Moreover, we found evidence for one new breeding area southeast of Greenland. Such geographically localised reproduction is relatively common in shallow-water squids, but is much less known

in deep-water squids. A localised reproduction linked to an increased food availability in the top layers of the open ocean may be especially important for *G. fabricii* because it would likely increase the survival of juveniles, while the surface currents might aid in their dispersal. Interestingly, no differences in sizes at maturity were found between the breeding areas, even between those located in the low sub-Arctic and in the Arctic. *Gonatus fabricii* apparently does not breed in the



Panel c) Biomass distribution of *Gonatus fabricii* in the Barents Sea based on results from Norwegian–Russian Barents Sea Ecosystem Surveys 2005–2015. (Modified from Zakharov DV, Strelkova NA, Manushin IE, Zimina OL, Jørgensen LL, Luybin PA, Nosova TB, Zhuravleva NE, Golikov AV, Blinova DJu (2018) Atlas of the megabenthic organisms of the Barents Sea and adjacent waters. Murmansk: PINRO press. [In Russian with English summary] Map on p 358)

Panel d) Increase of  $\delta^{15}\text{N}$  values and trophic levels during ontogenesis of *Gonatus fabricii*. (Modified from Golikov et al 2018)

Barents Sea, as the breeding areas are always located in the deep-sea parts of the Arctic and northern North Atlantic Oceans.

Previously *G. fabricii* only inhabited the western part of the Barents Sea, reaching  $-40^{\circ}\text{E}$ , during the non-breeding stage of its life cycle. However, due to climate warming, *G. fabricii* has expanded since 2004 to inhabit the entire Barents Sea and the western part of the Kara Sea. Still, only immature and early-maturing specimens are found in the Barents Sea. The maximum biomass of *G. fabricii* in the Barents Sea was nearly 25 000 tonnes with an abundance of 1.7 billion specimens

in 2011. The areas where biomass density exceeded  $100\text{ kg/km}^2$  and abundance exceeded  $10\,000\text{ specimens/km}^2$  were concentrated in deep-sea troughs in the marginal parts of the Barents Sea and in adjacent areas with depths over 500 m. But this spatial concentration of *G. fabricii* could not be correlated with the climatic state of the Barents Sea in 2009–2012.

*Gonatus fabricii* descend from surface water layers to the deep sea during ontogenesis, i.e. as the individual grows and matures. Thus, small juvenile squid live near the surface, and large adult squid dwell in the deep sea. During this descent,

females' tissue becomes jelly-like; they lose their tentacles and most of their ability to move around, and they cease feeding. We found that the gonads of female *G. fabricii* contained between 8 862 and 16 200 oocytes - precursor cells from which eggs develop. Younger females had more egg precursors, as up to 23.5% of all oocytes are resorbed into the body during the later phases of ontogenesis.

As mentioned earlier, the larger a squid is, the deeper it lives. *Gonatus fabricii* changes its diet from crustaceans to fish as it grows. Our stable isotope analysis showed that *G. fabricii* transitions 2.6 trophic levels higher in the food web through its life cycle, from surface-dwelling juvenile forms to large deep-dwelling adults.

The trophic level of *G. fabricii* was assessed using the most abundant herbivorous copepods as a baseline, *Calanus finmarchicus* in Greenland and *C. glacialis* in the Barents Sea. The trophic levels of squid range between 2.5 and 5.1. Thus, large adult specimens living in the deep sea are comparable to the Arctic's top vertebrate predators, such as seals, toothed whales, and large fish-eating or benthic scavenging fishes. This means that *G. fabricii* is a top invertebrate predator in the Arctic. At the same time, *G. fabricii* is also important prey: small juveniles living near the surface are preyed upon by many fishes and seabirds; large adults living at depth are preyed upon by toothed whales and large specimens of seals that are able to dive deep enough. Overall, 46 species of predators are known to feed on *G. fabricii*, although most feed on the small stages.

To understand the marine food web, it is important to estimate the stages at which squid are eaten by predators, and their total biomass. Fortunately, squid beaks remain intact for long periods in predators' stomachs, from which they can be collected, analysed, and measured. That means that equations can be used to estimate the size and biomass of *G. fabricii* based on its beak size, for all the Arctic, and specifically for West and East Greenland, and the Barents Sea. ■

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Golikov AV, Sabirov RM, Lubin PA (2017) First assessment of biomass and abundance of cephalopods *Rossia palpebrosa* and *Gonatus fabricii* in the Barents Sea. *Journal of the Marine Biological Association of the United Kingdom*, 97:1605-1616. doi:10.1017/S0025315416001004

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Kristina Baer // Arctic Council Secretariat

Sebastian Gerland // Norwegian Polar Institute

Rolf Rødven // Arctic Monitoring and Assessment Programme

# Making sea ice a ministerial matter

## SCIENCE AND SOCIETY

From space, the Arctic sea ice cover appears as a white surface, retracting and extending with the seasons. Every year in September, it reaches its minimum area, which has been decreasing over the past decades. Yet the sea ice extent alone is an incomplete indicator of ongoing changes in the Arctic.

“**W**E CANNOT DETERMINE THE STATUS of Arctic sea ice by only observing if a region is covered by ice or not. In satellite images from two consecutive years the ice extent could look very similar, but this tells us nothing about the properties of the ice, how thick it is and how old,” says Sebastian Gerland, geophysicist and section leader at the Norwegian Polar Institute in Tromsø.

During their expeditions to Svalbard, the Barants Sea, and the Fram Strait, Gerland and his colleagues have been collecting sea ice data for more than two decades. This time span has seen a substantial thinning of Arctic sea ice. “We increasingly find younger sea ice that has formed the same year. These young floes are more susceptible to different forcings. For example, they reflect less and absorb more solar radiation than older ice floes, and thus they are more likely to melt.”

These findings feed into Gerland’s scientific publications on sea ice – its thickness, optical proper-

ties, and snow cover (to just mention a few). But how do his and his collaborators’ findings about ice make their way to the public, and – more specifically – into the hands of those who are making decisions?

One way is through scientific assessments and their summaries for policymakers: compilations of state-of-the-art knowledge that – for example – reflect the current changes in the Arctic, including their impacts in and beyond the Arctic, identify knowledge gaps, and formulate recommendations for action.

A landmark assessment for the Arctic was the 2005 Arctic Climate Impact Assessment (ACIA). The report was produced by the Arctic Monitoring and Assessment Programme, one of six Working Groups of the intergovernmental Arctic Council. Some 300 scientists, experts, and representatives for Indigenous peoples collaborated to develop a comprehensive, multidisciplinary account of





climate change in the Arctic. The result is probably one of the most widely read documents focused specifically on the Arctic, and one of the world's first in-depth regional accounts of climate change impacts.

ACIA was also Sebastian Gerland's entry point to the work of the Arctic Monitoring and Assessment Programme (AMAP). "At that time I was working on the albedo feedback of sea ice - the processes ice triggers when it reflects sunrays. In 2003, we organised a workshop on Arctic climate feedback mechanisms as a contribution to ACIA, which is how I got more familiar with the ongoing assessment work."

Gerland became a member of AMAP's climate expert group and was soon invited to join the work on a sea ice chapter for the subsequent climate

Scientist Sebastian Gerland retrieving a sea ice core drilled in Arctic sea ice north of Svalbard. Sea ice samples are taken for various measurements related to sea ice physics, chemistry and biology.

*Photo: Tor Ivan Karlsen / Norwegian Polar Institute*

assessment with focus on the cryosphere: Snow, Water, Ice and Permafrost in the Arctic (SWIPA). The first SWIPA assessment was published in 2011 and reported, amongst other things, on the "thinning of the ice cover and loss of old ice types" and the ecological, social and economic impacts this had. A second, updated SWIPA report followed in 2017.

"Working on the SWIPA assessments was a highly rewarding experience," says Gerland. "Cooperating with scientists from different countries and scientific disciplines opened my eyes to a larger



AMAP's Chair Anders Turesson, Rolf Rødven and Margot Wallström, at that time Sweden's Minister for Foreign Affairs, speak about AMAP's Arctic Climate Change Update at the Ministerial meeting in Rovaniemi, Finland. Photo: Nina Ågren / Arctic Council Secretariat

context. I could see how my work on sea ice fitted into the bigger picture, how sea ice physics affected other systems and processes, and how thinning sea ice affected both people and the ecosystem.”

Together with over a hundred scientific experts nominated by their countries to contribute to the report, Gerland reviewed the best available knowledge on the Arctic cryosphere for the SWIPA 2017 assessment and synthesised it into 270 pages. This scientific exercise followed specific guidelines, as AMAP's executive secretary Rolf Rødven explains: “The most important principle for AMAP assessments is that of scientific integrity. All reports are peer reviewed to guarantee the scientific standard. But in addition, we make sure that our reports embrace the diversity of knowledge on the Arctic - also including Indigenous and local knowledge.”

In order to ensure that all relevant data have been considered and authors have not been biased, the review process starts with a national data check and ends with an examination by independent referees. The result of this process is a compre-

hensive scientific report, a summary of current scientific knowledge on Arctic change: a tome weighing more than a kilogramme. Arguably too dense - both literally and figuratively - for busy policy makers. So, how can they be reached?

“Based on this compiled knowledge, scientists develop a scientific summary which also is the basis for a set of policy recommendations. Both documents go into a brief summary for policy makers. The policy recommendations are sent to the national representatives of the Arctic states, who review and discuss the suggestions. When consensus is reached on the policy recommendations, this summary is ready to be presented,” explains Rødven.

The final assessment and its summary are presented to ministerial-level representatives of the eight



Arctic States. The Ministers of Foreign Affairs of these states met most recently in Rovaniemi, Finland, in May 2019. AMAP's Arctic Climate Change Update 2019, which draws and builds on the SWIPA 2017 assessment, did not go unnoticed.

“On my way here, I read the [AMAP] Arctic Climate Change Update 2019, highlighting new findings,” said Margot Wallström, who at that time was Sweden's Minister for Foreign Affairs. “Annual air temperatures in 2014 to 2018 were all greater than any year since 1900. Sea ice volume in September [is] declining by 75 percent since 1979.” The Update provided a glimpse of knowledge based on hundreds of scientific publications – a glimpse that can make a difference.

Sebastian Gerland sums it up: “Assessments and their summaries trigger a process: people start to discuss topics, find out more about Arctic change, and pay attention to developments they might have been unaware of previously. Assessments and summaries build a foundation for knowledge-based decision-making and at the same time are a guide for future research.” ■

Margot Wallström, at the time Sweden's Minister for Foreign Affairs, speaks at the Arctic Council 11th Ministerial meeting in Rovaniemi, Finland, in May 2019. Photo: Jouni Porsanger / Ministry for Foreign Affairs, Finland

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#### FURTHER READING:

AMAP's Arctic Climate Change Update 2019 can be read and downloaded at <https://www.amap.no/documents/download/3295/inline>

AMAP's Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017 report can be read and downloaded at <https://www.amap.no/documents/download/2987/inline>

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Ellen Kathrine Bludd // UiT The Arctic University of Norway

# Drifting with ice – From the schooner *Fram* to ultramodern RV *Polarstern*

## RETROSPECTIVE

In 1893 the Norwegian researcher Fridtjof Nansen sailed his wooden schooner *Fram* towards the Arctic. He let the vessel freeze into an ice floe and drift, hoping that the natural east-west currents in the Arctic Ocean would carry *Fram* and her crew to the geographical North Pole.

**N**ANSEN NEVER DID REACH THE NORTH POLE, but his expedition was ground-breaking and unique in the history of science. Now the MOSAiC expedition, taking a similar approach, may elevate current climate science. The technology being used in MOSAiC is light years ahead of Nansen and his team. Nevertheless, Nansen started it all.

“People thought Nansen was mad,” says Harald Dag Jølle, polar historian from the Norwegian Polar Institute. “They thought he would self-destruct in his attempt to drift with the polar ice to the North Pole.” Jølle explains that many believed this impossible, as the North Pole was assumed to be on land. The harsh Arctic conditions alone would destroy Nansen.

Nansen declared that survival depended on only two things: enough food and proper clothing. However, he could not dismiss the brute force of the drifting ice. Yet Nansen thought to himself: “No ship has ever been constructed for this purpose, so if the ship is designed properly, it could work.”

He joined forces with shipwright Colin Archer and sailor Otto Sverdrup. The result was a ship Nansen named *Fram*, which is the Norwegian word for “forward”. She was a broad-beamed, round-bottomed schooner with a steam engine. The wooden ship had a length of 39 metres, and was 11 metres wide. *Fram* was an unusually wide ship with an unusually shallow draught, to better withstand



Nansen and his crew on board the wooden ship *Fram*.

*Photo: National Library of Norway*



Nansen reads the temperature from the water sampler.

*Photo: National Library of Norway*



Nansen on the drifting ice looking towards his ship *Fram*.

*Photo: National Library of Norway*



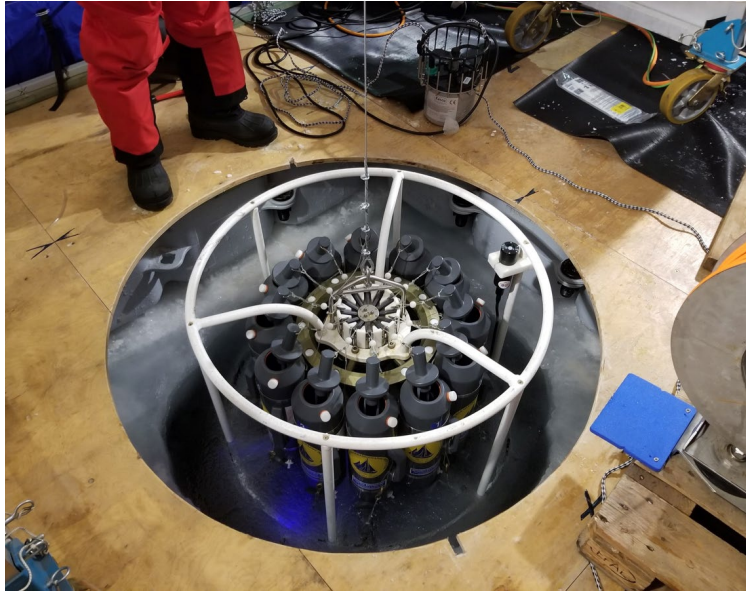
The logistics of the MOSAiC expedition is elaborate. Here are a few crew members in front of the *Akademik Fedorov*, one of the icebreakers that are supporting the expedition. *Polarstern* is also supported by air. The ship has its own landing pad for helicopters, and a landing strip for small planes has been prepared on the ice.  
 Photo: Mario Hoppmann / MOSAiC

the forces of the pressing ice. On board were 13 crew members: a couple of very experienced sailors, a doctor, a botanist, a naval lieutenant, two engineers, a mechanic and a few others.

“Nansen contributed greatly to the scientific knowledge about the Arctic and also to knowledge about global ocean currents in general,” explains Nansen expert Jølle. “When Nansen returned to the coast of northern Norway, he first sent a telegram to his wife to tell her that he had returned safely. His second telegram went to Waldemar Christopher Brøgger, professor of Geology at the University in Kristiania (Oslo) saying: ‘I am coming, overloaded with scientific data!’”

Harald Dag Jølle is currently writing a sequel to his book about Nansen.

Ocean city is the part of the research site on the ice that focuses on the water measurements. The CTD unit in this photo is the sampling unit that is comparable to the Nansen water sampler. But the CTD is of course far more advanced and sends water data to a computer in real time. This research site is located in a blue tent with a 1.4x1.4 metre ice hole for the CTD measurements. This is our closest science station, located only 400 metres away from *Polarstern*. Photo: Ying Chih Fang / MOSAiC



## FORCE OF STEEL

Even as we read, the MOSAiC expedition is following in Nansen's footsteps: for an entire year, a modern research vessel is drifting with an ice floe - hopefully towards the North Pole. The data gathered will be used by researchers all over the world, to take climate science to a completely new level.

The ship that the MOSAiC expedition is sending to follow Nansen's example is research vessel *Polarstern*, a German ship commissioned in 1982. She is still one of the world's most advanced and versatile polar research ships. Thanks to special technical details, this vessel can handle the conditions of the grand MOSAiC expedition during a complete Arctic winter. She is capable of operating in the pack-ice zone, but because of her double-walled steel hull and 20 000 horsepower engines, she can also easily break through 1.5-metre thick ice and overcome thicker ice by ramming.

Matthias Forwick, head of the Geoscience Department at UiT The Arctic University of Norway, has already been on eight expeditions with the *Polarstern*: four to the Arctic and four to Antarctica. He describes the *Polarstern* as a very special boat.

"A colossal lump of steel! And very well maintained in spite of her age," he says. "The ship is very flexible and can perform all kinds of research because it can be adapted to the activities the scientist wants to conduct."

The expedition, which set out from Tromsø in September 2019, can provide many new answers. Forwick adds that merely planning the logistics for such a large expedition in the Arctic Ocean is a feat. "Everything must be packed and stored very carefully aboard the boat, because once they have departed, there's nowhere to dock. It is an unparalleled logistical achievement."

## SIX HUNDRED PEOPLE FROM TWENTY NATIONS

As soon as the *Polarstern* had anchored at an ice floe, a small city appeared on the surface of the ice. Though the MOSAiC researchers don't live on the ice, that is where they conduct much of their research. Several instruments for measuring various parameters related to climate, ice, and air have been placed on the floe. This operation alone took about two weeks. An airstrip where small airplanes can land was also created on the ice, and there is a helicopter landing pad on board the ship. The expedition is supported by four other icebreakers, in addition to *Polarstern*.

Inside the *Polarstern* are various scientific labs where international experts conduct research across five main areas of interest: atmosphere, ocean, sea ice, ecosystem, and biogeochemistry. At all times, about 100 scientists will be working full time on board the ship. Personnel will be exchanged during different phases; over the course of the year, a total of 600 experts from 20 different countries will spend time on *Polarstern*. In addition, 300 people work in the background to make the expedition possible. Rolf Gradinger, professor of Arctic and Marine Biology at UiT, is one of those people.

Gradinger leads the ecosystem part of the MOSAiC expedition. He explains that a few years ago, the expedition was just an idea on a piece of paper.

“I find it incredible that this expedition is actually happening. That is a success in itself,” says Gradinger. “This is an amazing collaborative effort between many nations, resulting in the largest Arctic expedition ever,” he explains enthusiastically.

Gradinger has been collaboratively planning this research expedition for more than four years.

“I have been leading the work on putting all the ecosystem research together and finding out what kinds of data need to be gathered for all the different projects. It all has to fit together and be coordinated. The various research teams have to talk to each other. With 600 colleagues from 20 different countries, this is a puzzle with many pieces.”

#### EARLY CLIMATE SCIENCE

“The *Fram* expedition made Nansen world famous mainly because he went farther north than anyone had ever been before. But the science alone made the expedition valuable,” says historian Harald Dag Jølle. “Before Nansen left for his expedition, scientists took for granted that the Arctic Ocean was shallow, and they thought there might be islands there. But Nansen discovered that the ocean was 4000 metres deep!”

“When *Fram* left the harbour in 1893, researchers knew more about the surface of the moon, than the area north of 85 degrees latitude,” says Jølle. “It was possible to study the moon through a large telescope.”

He explains that when Nansen was measuring the depth of the Arctic Ocean, the crew had to fuse together every piece of rope and wire on board the ship in order to reach the bottom.

“It was a big surprise when the sounding line showed the astounding depth of 3900 metres! No one ever imagined that,” says Jølle.

The fact that there was a lot more water in the Northern Hemisphere than previously assumed made Nansen realise that the Arctic Ocean played a more important role in regulating the global climate than anticipated.

Jølle explains: “Nansen understood that our knowledge about the world’s oceans was vastly inadequate, especially considering that most of the planet is covered by water and that the oceans greatly impact the global climate. In a way, the *Fram* expedition was the start of the global climate research that we see as so important today. Nansen’s discoveries about global ocean currents was also important.”

#### MEASURING INSTRUMENTS

“Nansen invented a type of water sampler that could be used to collect water at great depths,” says Harald Dag Jølle.

The original Nansen bottle consisted of a metal cylinder attached to a cable. When the bottle had been lowered to the desired depth, a weight was dropped down the cable, triggering mechanisms that turned the bottle upside down and closed valves at the ends. The bottle and the water sample trapped inside it could then be retrieved by hauling in the cable. The temperature of the ocean at the depth where the water was sampled could





be determined with a “reversing” thermometer attached to the bottle. When the thermometer is inverted, its mercury column is trapped, showing the ambient temperature until the bottle has been hauled up and it can be recorded.

“Nansen made invaluable measurements of both temperature and salinity - salt content - from the depths of the Arctic Ocean,” says Jørgen Berge, professor of Arctic and Marine Biology at UiT. “His measurements and descriptions of the oceanography of the Arctic Ocean still stand strong. Today we use a CTD that measures temperature and salinity directly at predefined depths.”

Researchers Marc Oggier and Julia Regnery working on the sea ice, with the research vessel *Polarstern* in the background, 9 October 2019. Photo: Marcel Nicolaus / MOSAiC

The device Berge is referring to is a descendant of the Nansen bottle, which simultaneously measures Conductivity, Temperature, and Depth, thus giving it the shorthand name CTD.

“Nansen had to retrieve a small volume of water from - say - 1000 metres depth in order to measure temperature and salinity on the ship,” explains Berge. “Nowadays, we send down a CTD-rosette that has a direct connection with a computer aboard the research vessel, which means we get measurements in real time. We can also use other platforms that measure and send these kinds of data in real time, such as an underwater glider - a small submarine we control by changing its buoyancy.”

#### ON THEIR OWN

Just like Fridtjof Nansen and his crew, the researchers on the *Polarstern* must handle unexpected events and challenges on their own when they are out on the ship frozen in the ice floe.

“We have a detailed agenda for the sampling and experiments that have to be conducted each day,” says Rolf Gradinger. “But we cannot control the weather and nature. A storm can cause major problems and delay work, and then our plans must be changed. However, there are many smart people on this expedition, and the crew is very experienced in the Arctic, so I think it will run smoothly.”

The scientists participating in the MOSAiC expedition will have limited opportunities to communicate with the world. Data transfer capacity must prioritise transmission of important research data. Thus, the participants will be fairly isolated from family and friends for long periods of time.

“The scientific team won’t be on the ship for a whole year,” Gradinger explains. “Every three months there will be an exchange of both scientific personnel and the ship’s crew. And fresh food will be supplied via other icebreakers or aircraft.”

#### IMPORTANCE FOR THE FUTURE

Gradinger does research on ice algae and other flora and fauna that live inside or close to the sea ice. Most of us think of the ice as an inhospitable place to live, but it is actually teeming with life!

“The sea ice is like a Swiss cheese with many holes and channels, perfect hiding places for many small creatures,” Gradinger explains. Today the list of sea ice inhabitants includes about 6500 bacteria, over 1000 algae and 50 animal species.

The Arctic is an epicentre for global climate change; temperatures are currently rising faster here than anywhere else on the planet.

“At present, we know very little about what impact the melting of sea ice can have for the species that live in the Arctic,” says Gradinger. “In order to ensure sustainable management of a changing Arctic, we need more knowledge about this large system.”

Although the last few decades have seen substantial progress in exploring the Arctic ecosystem, its functioning remains poorly understood, and the MOSAiC scientists can make vital contributions. The year-round sampling and experimental work of biologists will provide unique insights into the entire food web.

“Nansen really wanted scientific measurements to be as precise as possible,” says Harald Dag Jølle. Nansen would most likely have approved of the MOSAiC expedition, with its highly advanced and precise instruments, taking Arctic science to the next level. ■



Fridtjof Nansen was very interested in obtaining accurate data from the Arctic, and would likely have enjoyed hearing about the MOSAiC expedition with its high-tech field sampling. *Photo: National Library of Norway*

#### **MOSAIC – MULTIDISCIPLINARY DRIFTING OBSERVATORY FOR THE STUDY OF ARCTIC CLIMATE**

The MOSAiC expedition is led by atmospheric scientists Markus Rex and Klaus Dethloff from the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, and Matthew Shupe from CIRES/NOAA.

The project budget is 140 Million Euros.

<https://mosaic-expedition.org/>

Åshild Ønvik Pedersen // Norwegian Polar Institute

Brage Bremset Hansen // Norwegian University of Science and Technology

# Long-term climate and reindeer monitoring show contrasting local trends

## RESEARCH NOTES

Svalbard reindeer live in the world's most rapidly warming environment. Long-term monitoring reveals contrasting trends in the abundance of reindeer in coastal and inland ranges. Decades of climate data suggest spatial variation in the strength of climate change effects on reindeer populations.



Photo: Sophie Cordon



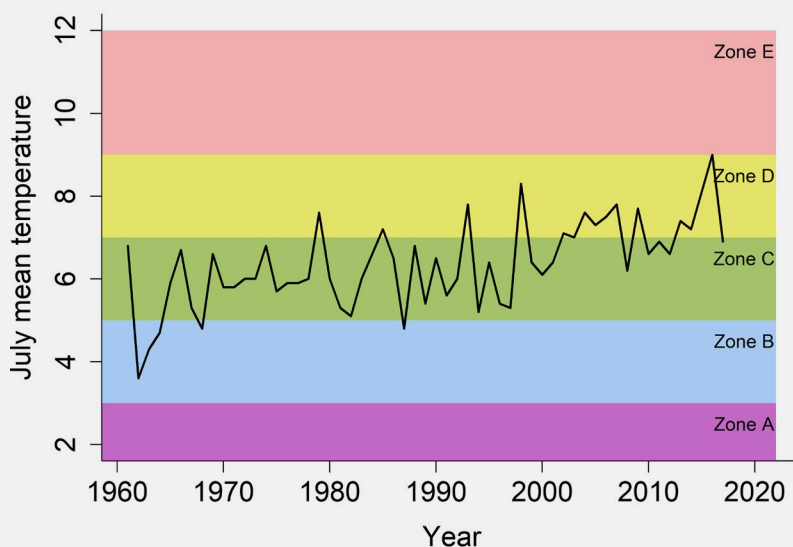
**T**HE SVALBARD REINDEER (*Rangifer tarandus platyrhynchus*) is a key herbivore in the Svalbard tundra ecosystem. After years of monitoring the size, and the sex and age structure of reindeer populations in coastal and inland regions we now have the longest time-series on Svalbard tundra species (www.mosj.no; www.coat.no). Combined with local weather records, these data allow us to investigate the effects of climate change in regions with contrasting weather variability and ecological characteristics.

### CLIMATE REGIME SHIFTS

Rapid climate change has taken place since the monitoring of the Svalbard reindeer started four decades ago (1978/79). During this period, the reindeer have lived through both periods of cold, stable winters in the 1980s, and more recent periods when the winters have often been mild and rainy. In addition, the reindeer have experienced considerable summer warming. These climate trends have accelerated in the current century.

Rainy winter weather often leads to formation of ground ice, encapsulating food plants in extensive ice sheets, which restrict forage access and result in increased mortality and reproductive failures. Recently, mild and rainy winters - and hence ice-locked pastures - have become the norm rather than exception, causing a linked climate-cryosphere regime shift due to rapid winter warming around the turn of the century.

Warmer summers change the characteristics of the growing season and “greenness” of plants, and scientists use July temperatures to delineate bioclimatic subzones in the Arctic. Changes in mean July temperature in Svalbard indicate that, climatically, parts of the Svalbard tundra have shifted an entire bioclimatic subzone, with implications for plant productivity. Given continued summer warming and sufficient moisture and nutrients, food for plant-eaters will likely become more abundant. In addition, if spring snowmelt continues to start earlier and the first snow of autumn falls later, the longer snow-free season will increase the overall carrying capacity of the Svalbard tundra for grazing reindeer.



The mean July temperature at Svalbard Airport meteorological station (1961-2017) plotted against the climatic boundaries of the Arctic bioclimatic subzones. A summer climate regime shift has been detected around 2000 in this part of Svalbard. This suggests a strong tendency for a shift from subzone C (Middle Arctic Tundra Zone) to subzone D (Southern Arctic Tundra Zone).  
Figure: Jane U Jepsen, Norwegian Institute for Nature Research



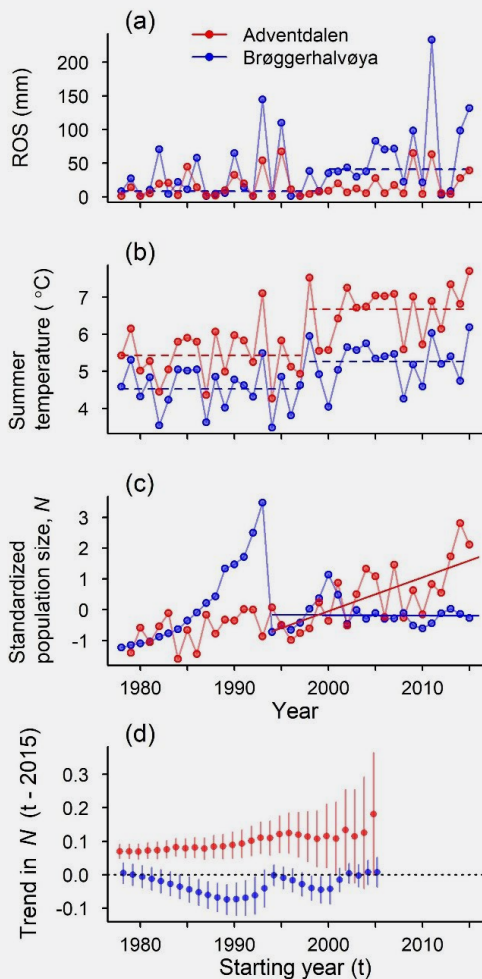
Photo: Ronny Aanes

## REINDEER DOUBLING

After humans discovered Svalbard in the late 16th century, over-harvest gradually exterminated the Svalbard reindeer in parts of the archipelago. In 1925, the population was very small (up to a thousand) and the reindeer was protected by law. About 60 years later, scientists estimated the population to be around 11 000 individuals. Recently, a study based on extensive field sampling estimated 22 000 reindeer in Svalbard. The apparent doubling strongly indicates an overall positive population trend.

However, annual monitoring suggests that population trends vary locally. For instance, in two of the core reindeer monitoring regions (Brøggerhalvøya

and Adventdalen), the populations show highly contrasting trends. After the re-introduction of 15 reindeer to Brøggerhalvøya in 1978, the population grew fast, numbering 360 individuals during the winter census of 1993. The population crashed to ~80 reindeer in the following winter due to a combination of heavy rain in early winter, over-grazed pastures, and very high population density (i.e. strong competition for food). The population has since fluctuated around low densities (~100 individuals), at least partly due to frequent rainy and icy winters. In contrast, the population in Adventdalen, which has a more “inland” climate regime, has increased more than three-fold since the census started in 1979 (459 reindeer), with a record high number in 2018 (1701 reindeer).



Time-series data (1978–2015) and population trends in the two of the core populations for long-term monitoring – Adventdalen (red) and Brøggerhalvøya (blue). Annual fluctuations in (a) rain-on-snow (ROS), (b) summer temperatures and (c) standardised reindeer population sizes, and the estimates of (d) population size trends (with varying trend-starting year; whiskers showing 95% CI). Meteorological data are obtained from the Ny-Ålesund weather station (blue) and Svalbard Airport weather station (red). Horizontal dashed lines in (a) and (b) denote detected regime shifts, i.e. change points in mean. The solid line in (c) shows the population size trends for the time-period after the irruptive population phase in Brøggerhalvøya (figure from Hansen et al 2019).

## WEATHER, CLIMATE, AND POPULATION TRENDS

Can climate and weather have the same effects on these two populations on an annual basis, while simultaneously causing long-term population trends to diverge? Annual fluctuations in winter rain essentially match the fluctuations in reindeer survival, reproduction and population growth rates across Svalbard. The annual growth rates of the reindeer populations in Adventdalen and Brøggerhalvøya also correlate with each other.

However, some small but important differences in how climate trends affect these two populations are evident (see graph to the left). First, the increase in the annual amount of “rain-on-snow” (ROS) was stronger in Ny-Ålesund (Brøggerhalvøya) than at Svalbard Airport (Adventdalen). Second, summer temperature has increased over time at both stations, but the increase was greater at Svalbard Airport (ca 1.3°C versus 0.9°C).

Rainier and icier winters slow reindeer population growth over time by reducing survival and reproduction. Warmer summers have a positive effect on population growth most likely because of increased food abundance and extended grazing seasons. The slight differences in climate trends in our two monitoring sites may partly explain the local differences in population trends. In other words, in Adventdalen, the positive effect of climate change in summer overrides the negative effect in winter, whereas the opposite seems to be the case in Brøggerhalvøya.

Thus, local differences in the impact of seasonal climate change may translate to local differences in how well the reindeer population does. In some places there will be losers, but in other places there will be winners. Seen overall, the patchy nature of climate change impacts may help ensure long-term survival of the Svalbard reindeer. ■



151 RAPPORTSERIE



## Svalbard reindeer

(*Rangifer tarandus platyrhynchus*)

### A status report



Ashild Ønvik Pedersen, Ingrid M. G. Paulsen, Steve Albon, Gustav Busch Arrntsen, Brage B. Hansen, Rolf Langvatn, Leif Egil Loe, Mathilde Le Moullec, Øystein Overrein, Sert Peeters, Virve Ravolainen, Erik Ropstad, Audun Stien, Nicholas J. C. Tyler, Vebjørn Veiberg, René van der Wal, Roy Andersen, Larissa T. Beumer, Isabella Eisele, Mads Forchhammer, B. Justin Irvine, Filippo Marolla, Gabriel Pigeon, Egil Reimers, and Liv Monica Trondrud

## SVALBARD REINDEER STATUS REPORT

This report summarises research on the Svalbard reindeer and outlines important knowledge gaps. The recent extensive and diverse scientific activity now allows a much better understanding than previously of how Svalbard reindeer have adapted to, and interact with, their High Arctic environment. This knowledge is crucial to understand how the species and ecosystem respond to the large environmental changes associated with climate change. The report summarises knowledge from scientific papers, reports, theses, books and anecdotes, mainly from the early 1970s up to the present.

<https://brage.npolar.no/npolar-xmlui/handle/11250/2629207>

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Hansen BB, Pedersen ÅØ, Peeters B, et al (2019) Spatial heterogeneity in climate change decouples the long-term dynamics of wild reindeer populations in the high Arctic. *Global Change Biology* <https://doi.org/10.1111/gcb.14761>

Le Moullec M, Pedersen ÅØ, Stien A (2019) A century of recovery from overharvest in a warming High-Arctic: the successful conservation story of endemic Svalbard reindeer. *J Wildlife Manage* 83:1676-1686 DOI: 10.1002/jwmg.21761

Peeters B, Pedersen ÅØ, Loe LE, et al (2019) Spatiotemporal patterns of rain-on-snow and basal ice in high Arctic Svalbard: detection of a climate-cryosphere regime shift. *Environ Res Lett* 14 <https://doi.org/10.1088/1748-9326/aaefb3>

Vickers H, Hogda KA, Solbo S, et al (2016) Changes in greening in the high Arctic: insights from a 30 year AVHRR max NDVI dataset for Svalbard. *Environ Res Lett* 11 <https://doi.org/10.1088/1748-9326/11/10/105004>

Elin Vinje Jenssen // Norwegian Polar Institute

# Dive deep into *The Ecosystem of Kongsfjorden, Svalbard*

NEW BOOK

Few people know as much about Kongsfjorden in Svalbard as Haakon Hop from the Norwegian Polar Institute. Ever since his first visit to Svalbard in 1981 as a young marine biologist, he has returned regularly to study algae and plankton. Hop, who is also an experienced research diver, investigates plant and animal communities of Kongsfjorden's bustling hard-bottom ecosystem.

**O**VER THE PAST TWENTY YEARS, his visits have become more frequent, enabling him to keep an eye on the effects of global warming on the west side of Spitsbergen. Today, Kongsfjorden at Ny-Ålesund is the most explored fjord in Norway, and perhaps in the world. It is a popular research laboratory for researchers from Norway and abroad.

But what makes scientists flock there?

“Kongsfjorden has a rare mixture of Arctic and Atlantic water and freshwater, as well as sediments that flow out from beneath the glaciers, mainly from the mighty terminus of Kongsbreen glacier,” explains Hop. “The climate has also become considerably warmer over a relatively short period of time, making the ecosystem here particularly

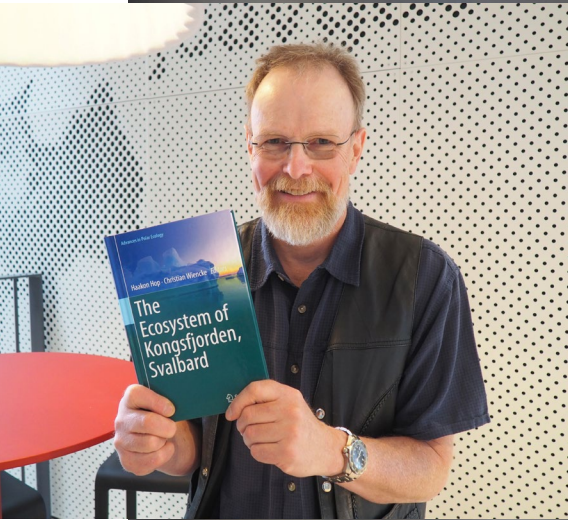
interesting for researchers. What happens to life in and around a fjord like this when the temperature changes?”

## **KONGSFJORDEN'S WATER HAS WARMED 2°C**

The answers are complex and there are currently more questions than answers. The temperature increase in Kongsfjorden has been rapid. Researchers are working diligently to discern changes in the ecosystem. But the already visible changes are indisputable.

For the last ten to twelve winters, sea ice has been nearly absent from Kongsfjorden, and increasing amounts of warmer Atlantic water have flowed into the fjord. Currently, the water in the fjord is about two degrees warmer than just a few years ago.

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Haakon Hop with the book *The Ecosystem of Kongsfjorden, Svalbard*, co-edited with his long-time collaborator, marine biologist Christian Wiencke of the Alfred Wegener Institute.  
*Photo: Elin Vinje Jenssen / Norwegian Polar Institute*



Little auks. *Photo: Geir Wing Gabrielsen / Norwegian Polar Institute*





Brünnich's guillemots in Kongsfjorden.

Photo: Helge Tore Markussen / Norwegian Polar Institute

“A two degree increase in ocean temperature is a lot and can affect the ecosystem,” says Hop. “However, with the help of modelling, we have also shown that the ecosystem can adapt to changes observed over more than a decade.”

#### **AN ECOSYSTEM UNDER A MAGNIFYING GLASS**

In the autumn of 2019, Hop released a book describing Kongsfjorden's ecosystem. In it, he and his long-time collaborator Christian Wiencke from the Alfred Wegener Institute in Germany, expound on Kongsfjorden's bustling community of algae and animals, and how temperature changes have affected and can affect the organisms that live in and depend on the sea, such as plankton and seabirds. The book also treats physical drivers and processes in the atmosphere and the sea, including hydrography, sea ice, and light climate.

“The book highlights all ecological aspects of the Kongsfjorden system, from the marine to the atmospheric environment, including long-term

monitoring, the ecophysiology of various species, the ecosystem's structure and function, ecological processes, and biological communities, both in the water masses and on the seabed,” says Hop.

#### **TEMPERATE SPECIES INVADING THE ARCTIC**

Kongsfjorden's rising temperatures have altered the composition of the biomass found in the fjord. Over the past decades, increasing numbers of Atlantic zooplankton have flowed in from the south and established themselves in the Kongsfjorden system, competing with the more energy-rich Arctic zooplankton species that thrive in colder waters. This can create imbalance and a lack of food in the ecosystem, especially for plankton-eating seabirds like the little auk.

Previously, the little auk has fed on local species of zooplankton, rich in lipids and nutrients.



Haakon Hop has knowledge of Kongsfjorden's ecosystem both as a researcher and a research diver. *Photo: Ole Magnus Rapp*

Haakon Hop with plankton samples collected during research expeditions to Kongsfjorden in 2017. *Photo: Martin Kristiansen / Norwegian Polar Institute*

However, the new prey species coming in from the south are smaller and less nutritious. Over time, this can affect the birds' survival.

“Atlantic zooplankton are smaller and contain less lipids than Arctic zooplankton. The Atlantic species are here in addition to the Arctic species that are already in the fjord. They are still present, but may be less numerous than before. Even though the Arctic ecosystem has the ability to maintain and repair itself, extensive changes in the relationship between Arctic and Atlantic species of zooplankton can have major consequences for predators,” says Hop.

#### INTERNATIONAL BOOK PROJECT

The initiative for the book project *The Ecosystem of Kongsfjorden, Svalbard* was taken at an international meeting about Kongsfjorden in 2014, which was led by Hop and Wiencke. The participants were asked whether they could write chapters for a book about the ecosystem of Kongsfjorden,

and the result has become an extensive work comprising 14 chapters written by a total of 82 authors from 10 countries, many of whom have themselves done research in Kongsfjorden.

The chapters summarise work conducted by researchers from many different institutions. And since the research has been going on for many years, several lengthy time series have been established. The book presents time series of atmospheric parameters, hydrographic data, sea ice measurements, phytoplankton and zooplankton.

The book (562 pages) was published by Springer in the series *Advances in Polar Ecology*. ■

The AMINOR Steering Committee: Martin Biuw, Marie-Anne Blanchet, André Frainer, Sandra Hamel, Benjamin Planque, Heli Routti, Eeva Soininen, Arnaud Tarroux and Nigel G Yoccoz

# AMINOR – the Fram Centre’s Research School for Environmental Research

## SCIENCE AND SOCIETY

Current environmental research and management build on knowledge from many different fields. AMINOR provides a communication and educational platform for students and scientists, focusing on the integration of monitoring, science, and management across several scientific disciplines.

**A**MINOR IS A MULTIDISCIPLINARY RESEARCH network connecting all flagship research programmes represented at the Fram Centre. The focal groups are PhD and master’s students, early career scientists, and researchers covering diverse disciplines such as statistics, oceanography, meteorology, terrestrial, freshwater and marine ecology, ecotoxicology, economics, ethics, political/social science, and history. AMINOR aims to increase, diversify, and improve skills and knowledge held in the Fram institutions. To this end, AMINOR creates opportunities for students and members of the Fram Centre to continually develop their knowledge and competences on study designs, analytical methods, and theoretical development through courses, workshops, and in-depth discussions.

Currently, four institutions from the Fram Centre are involved in AMINOR’s steering committee, working together to continue the development of the research school. However, AMINOR intends to achieve its goals collectively and across institutional boundaries to benefit from the experience, knowledge, and networks available at each institution. All Fram Centre institutions are thus strongly encouraged to take part in AMINOR’s activities.

Because of the cross-institutional nature of AMINOR, we constantly strive to improve communication among our members. We use two main tools: our web site ([www.coat.no/en/Education/Aminor](http://www.coat.no/en/Education/Aminor)) and a Slack workspace for more instantaneous and direct communication (<https://aminor-fram.slack.com>).



During the AMINOR workshop on food webs, 8-11 October 2019. Photo: André Frainer

You can sign up for the AMINOR Slack workspace if you have an email address from a Fram Centre institution. Alternatively, send an e-mail to [arnaud.tarroux@nina.no](mailto:arnaud.tarroux@nina.no), so we can register you. This will give you access to all the activities organised by AMINOR, allow you to participate in discussions, and - not least - be notified about upcoming events at the Fram Centre and elsewhere. Informing scientists at other institutions about interesting guest lectures, thus enabling them to participate, is easy via the AMINOR Slack workspace. You can also exchange messages directly with any AMINOR member. The workspace also lets you create “channels” for specific topics to foster dynamic group discussions. Students are especially encouraged to become involved and participate in all of our activities!

#### AMINOR IS CURRENTLY CO-LED FROM FOUR INSTITUTIONS AT THE FRAM CENTRE:

UiT The Arctic University of Norway (UiT), the Norwegian Institute for Nature Research (NINA), the Institute of Marine Research (IMR) and the Norwegian Polar Institute (NPI). The AMINOR Steering Committee includes, in alphabetical order: M Biuw (IMR), MA Blanchet (UiT), A Frainer (NINA), S Hamel (Laval University/UiT), B Planque (IMR), H Routti (NPI), E Soininen (UiT), A Tarroux (NINA), and NG Yoccoz (UiT).

These are the main AMINOR activities proposed so far (but suggestions are welcome):

- **Group discussions** (2-4 hours) assessing and reflecting on analytical methods and conceptual advances linked to central problems within different monitoring and management schemes
- **Courses** within the portfolio of master's/ PhD students in environmental studies
- **Weekly lunch discussions** with seminar presentations or discussions based on recent literature
- **Workshops** (2-4 days) where students, researchers, and invited guests gather to deepen knowledge on specific topics that are of interest to a broad range of researchers within the Fram Centre

In 2019 AMINOR organised numerous **group discussions** based on a series of scientific articles and presentations by guest researchers. Topics included: statistical evidence; global meta-analysis on biodiversity; species distributions and conservation; citizen science and population distribution trends; cascade effects in ecosystems; recreational ecology; ecosystem consequences of balanced fishing regimes; integral projection models (i.e. models of population dynamics based on individual parameters such as size) and their relevance for evaluating the impacts of pollutants; and challenges in transferability of ecological models. In 2020, we plan to organise up to six such morning/afternoon discussions.

AMINOR organises **weekly lunch discussions and seminars**. The topics are either based on recent papers suggested by members, or on presentations, typically given by visiting scientists or early-career scientists and students at the Fram Centre. Visiting scientists who have held lectures include Jay Piggott (Ireland) on “Climate change and multiple stressors in freshwater ecosystems”, Gretta Pecl (Australia) on “Range shifts in marine fish due to climate warming”, and Andreas Bruder (Switzerland) on “Food webs and multiple stressors”. We have also participated via video link

in seminars held elsewhere, such as the citizen science talks presented at a conference arranged by the Norwegian node of the Global Biodiversity Information Facility. All lunch discussions were physically held at both UiT and the Fram Centre building, with a video link to facilitate participation from both Fram Centre hubs.

AMINOR holds two core **PhD courses** at UiT: “Ecological methodology: study design and statistical analysis” (BIO-8105, arranged every year) and “Environmental systems: integration of monitoring, research and management” (BIO-8006, arranged every other year). These courses are well established and fully integrated in the UiT course curriculum.

**Two workshops** were also successfully held by AMINOR in 2019, on “food web analysis” and on “citizen science”.

AMINOR strongly encourages researchers and students from other Fram Centre institutions not yet represented in the steering committee to become members: this will help AMINOR tailor activities to the diversity of disciplines represented at the Fram Centre. ■

AMINOR wishes to thank Sandra Hamel for her instrumental role in setting up AMINOR and carrying the research school to where it is today. Although Sandra has left UiT for a new adventure at Université Laval in Québec, Canada, she remains involved in AMINOR.

#### AMINOR activities depend entirely on external funding

In 2019, AMINOR received support from three Fram Centre flagships: (i) Hazardous substances, (ii) Climate Effects on Terrestrial Ecosystems, Landscapes, Societies and Indigenous People, and (iii) MIKON – Environmental Impacts of Industrial Development in the North. Each flagship contributed 30 000 NOK for the year 2019.



Helge M Markusson // Fram Centre

# The Arctic at risk from plastic

## RESEARCH NOTES

A research report presented in 2019 shows that the Arctic is under threat and may suffer negative impact if plastic enters the food chain.

Researchers Claudia Halsband from Akvaplan-niva and Dorte Herzke from NILU – Norwegian Institute for Air Research have reviewed currently available published research on plastic pollution in the Arctic. The studies show that this new type of pollution is causing problems even in areas far from the densely populated parts of the world.

“Despite the fact that the research covers a vast geographical area and is based on varying methods, it is appar-

ent that plastic is ubiquitous in Arctic environments,” confirm Claudia Halsband and Dorte Herzke.

The increase in the volume of plastic litter is directly related to the increase in plastic production every year. When mass production of plastic started in the 1950s, annual production volumes were less than 2 million tonnes; 335 million tonnes were produced in 2016.

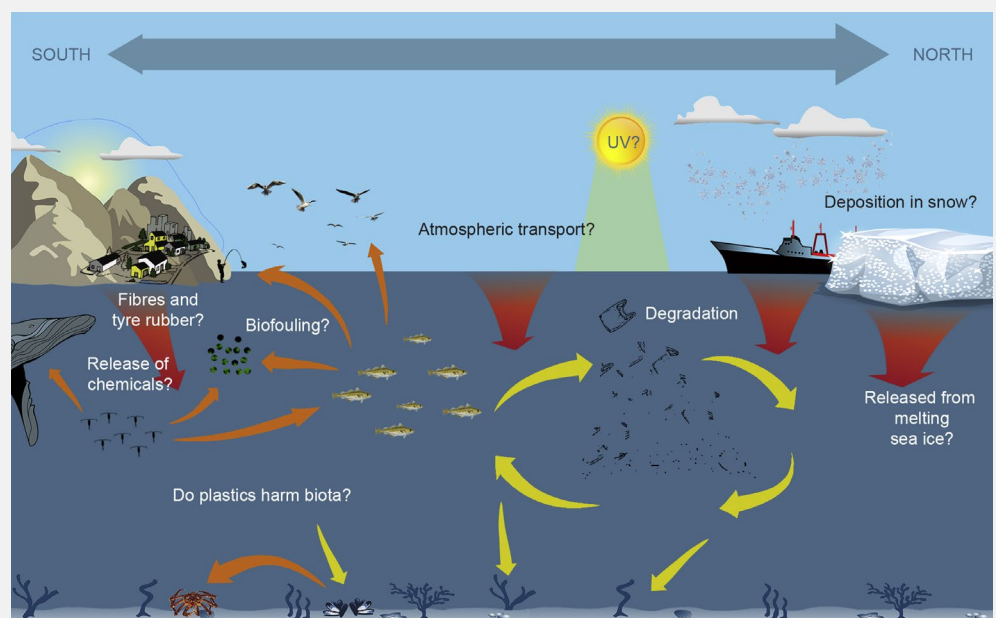
Plastic pollution in general – and in the world’s oceans in particular – has emerged as a major environmental problem worldwide, and is now acknowledged as a threat to all ecosystems. More recent estimates suggest that 5-12 million tonnes of plastic end

up in the world’s oceans every year.

The data reviewed by the researchers in Tromsø show that the impact of plastic litter pollution is just as severe in the Arctic as in more populated areas farther south. Further studies are required to uncover whether this is particularly the case for the European Arctic, which has a huge influx of water from the Atlantic Ocean.

The research is funded by the Arctic Monitoring and Assessment Program (AMAP) and the Fram Centre’s Flagship programme “Hazardous substances – effects on ecosystems and human health”.

Examples of knowledge gaps regarding distribution, transport, and impact of plastic litter in Arctic systems. Red arrows = plastic litter input, yellow arrows = transport pathways, orange arrows = food web transfer. *Diagram: Claudia Halsband and Dorte Herzke*



Ann Kristin Balto // Norwegian Polar Institute

Photo: John Snuggerud // Norwegian Polar Institute

# At the dentist in Antarctica

## RETROSPECTIVE

Early in 1957, 14 Norwegians and 42 Greenland husky dogs were set ashore in Dronning Maud Land, Antarctica. Much can go wrong over the course of three years, and medical equipment and a doctor were very important parts of extended scientific expeditions.

**H**AAKON SÆTHER WAS THE DOCTOR during the first winter. Included among the medical supplies were painkillers, apparatus for measuring blood sugar levels, a device to measure carbon monoxide and vials to counteract carbon monoxide poisoning, various scalpels and saws for amputation, as well as dental equipment. No serious incidents occurred during the first winter.

The following year, staff rotation brought in new crew members and a new doctor. Soon after arriving in Antarctica, the doctor, Anders Vinten-Johansen, had to moonlight as a dentist. In this photo, expedition leader Sigurd Helle is receiving dental surgery with the aid of a foot-driven drill. Pumping on the pedal, Dr Vinten-Hansen powered a small drill rotating at 600-800 revolutions per minute, making it possible to fill Sigurd Helle's teeth.

Most of the winter was quiet for the doctor, but only a week before the relief boat *Polarbjørn* was to weigh anchor for the return trip to the north in 1959, disaster struck. Assistant meteorologist Bjørn Grytøyr and steward Sverre O Pettersen set out with a team of dogs to the auxiliary station. When they were preparing to return the next day, the dogs were unsettled and difficult to get started. Then, abruptly, all the dogs set off running at once, dragging heavily on a trace that had become entangled around Pettersen's right leg. The powerful jerk caused a complicated and painful fracture. Pettersen was transported back to the cove of Polarsirkelbukta and carried on board *Polarbjørn*. The doctor was unable to do anything but administer appropriate doses of painkillers, and Pettersen received treatment at a hospital in Cape Town three weeks later. Unfortunately, the operation was unsuccessful and Pettersen had to undergo a new operation at a hospital in Oslo.



Toothache means only one thing: start drilling! Doctor Anders Vinten-Johansen is drilling expedition leader Sigurd Helle's teeth. Photo: John Snuggerud / Norwegian Polar Institute

Background: During the 1950s, the world's nations initiated a huge scientific project called the International Geophysical Year (IGY), which lasted from July 1957 to December 1958. Special focus was placed on the polar regions. Norway participated and established Norway Station in Dronning Maud Land. The expedition was led by Sigurd Helle from the Norwegian Polar Institute. The original plan was to stay for two entire winters, but the expedition was extended to a third year. Six decades after the signing of the Antarctic Treaty, Antarctica is the only continent in the world where the management plan stipulates that

it must be used for peaceful purposes only. Active research work allows parties to participate in decision-making regarding the Antarctic cooperation. Sixty years of international research efforts are now bearing fruit, bringing new knowledge to light.

Images from the Norwegian Antarctic Expedition 1956-1960 can be found in the Norwegian Polar Institute's photo archives: <https://bildearkiv.npolar.no>. An exhibition on research in Antarctica can be viewed in the foyer of the Fram Centre. ■

# The Fram Centre wins environmental protection award

## NEWS ITEM

The Fram Centre was awarded the 2019 UNI Foundation's Environmental Protection Award in December.

The UNI Foundation's Chairman of the Board, Paul J Manger, highlighted that the Environmental Protection Award had been given based on the importance of the work that the Fram Centre is doing within the fields of climate and environmental research in the north. Another decisive factor in the decision was that the knowledge Fram Centre researchers provide benefits society.

The UNI Foundation's main objective is to promote activities that are generally beneficial within the fields of damage prevention and environmental protection, thus contributing to the safe development of Norwegian society. The UNI Foundation seeks to achieve this objective mainly by awarding financial support for projects and giving recognition to institutions and individuals.

This year, the Environmental Protection Award is one of two that are awarded based on nominations. The winning nominee receives NOK 500 000. The second prize, the Damage Prevention Award, was awarded to the Norwegian Association for Children's Palliative Care, which works to increase knowledge and improve the palliative care given to children in Norway who are living with life-shortening or life-threatening health conditions.



The Environmental Protection Award was awarded during an event at the Continental Hotel in Oslo in December. The UNI Foundation's Chairman of the Board, Paul Manger, flanked by the Fram Centre's Managing Director Frode Kjersem (left) and Outreach Coordinator Helge Markussen.

*Photo: The UNI Foundation*

## AN HONOUR AND AN INCENTIVE

"It is a great honour for the Fram Centre to be nominated and to receive this award," says Cathrine Henaug, who chairs the Committee of Institutional Directors at the Fram Centre.

"We really appreciate that the research work conducted by the institutions here at the Fram Centre is being noticed and recognised with such an

award. The environment and climate are very important areas of research and the relevance of research within these areas is rapidly increasing in step with the changes we see in the global climate. The award will be a great incentive to continue the research work taking place at the Centre, across fields of expertise and disciplines," says Henaug. ■



Cathrine Henaug (left) takes over from Anne Husebekk as head of the Committee of Institutional Directors at the Fram Centre.

*Photo: Helge M Markusson / Fram Centre*

## New managers at the Fram Centre

### NEWS ITEM

In October 2019, Cathrine Henaug from the Norwegian Institute for Nature Research (NINA), was elected head of the Committee of Institutional Directors – *sentermøtet*. She succeeds Anne Husebekk, rector at UiT The Arctic University of Norway, who held the post for five years.

Cathrine Henaug works as research manager at NINA's division at the Fram Centre.

*Sentermøtet* is the chief body of the Fram Centre, and comprises managers from 21 member institutions, as well as representatives from the Ministry of Climate and Environment and the Ministry of Trade, Industry and Fisheries. This committee sets the overall strategic priorities for the Fram Centre.

In September 2019, Eldbjørg Heimstad from NILU – Norwegian Institute for Air Research was elected to lead the Fram Centre's Research Management Group. She takes over from Anita Evenset of Akvaplan-niva AS.

The Research Management Group is the Fram Centre's chief body for research management. It is comprised of one appointed representative from each of the 21 participating institutions that wish to participate, as well as the managers of the Fram Centre Flagship Research Programmes. Alma Thues-tad from the Norwegian Institute for Cultural Heritage Research was elected vice-chairperson of the Research Management Group. ■



In keeping with the show's historical approach, the models and researchers were joined by the great Norwegian explorers. From left: Pernilla Carlsson, John Lukas Somby and Linda Hanssen. *Photo: Sverre Simonsen*



Pole dancer Elise Dahl-Hansen boosted the show in her own way, placing focus on research about climate and environment in the High North. *Photo: Sverre Simonsen*

Helge M Markusson // Fram Centre

# Cultural expression for scientific outreach

## SCIENCE AND SOCIETY

Cartoon movie star Laila and pole dancers. For nearly a decade, researchers at the Fram Centre have enlisted artists, musicians, writers, and entertainers to help spread the knowledge they have acquired. Here are three recent examples.

### THE GREAT ARCTIC FASHION SHOW

Who could imagine scientists dancing on the same floor as fashion models and pole dancers? In September, they did exactly that. Linda Hanssen from NILU - Norwegian Institute for Air Research, Pernilla Carlsson from the Norwegian Institute for Water Research, and Unni Mette Nordang from the Centre for the Ocean and the Arctic rose to the challenge and took part in “The Great Arctic Fashion Show” in Tromsø.

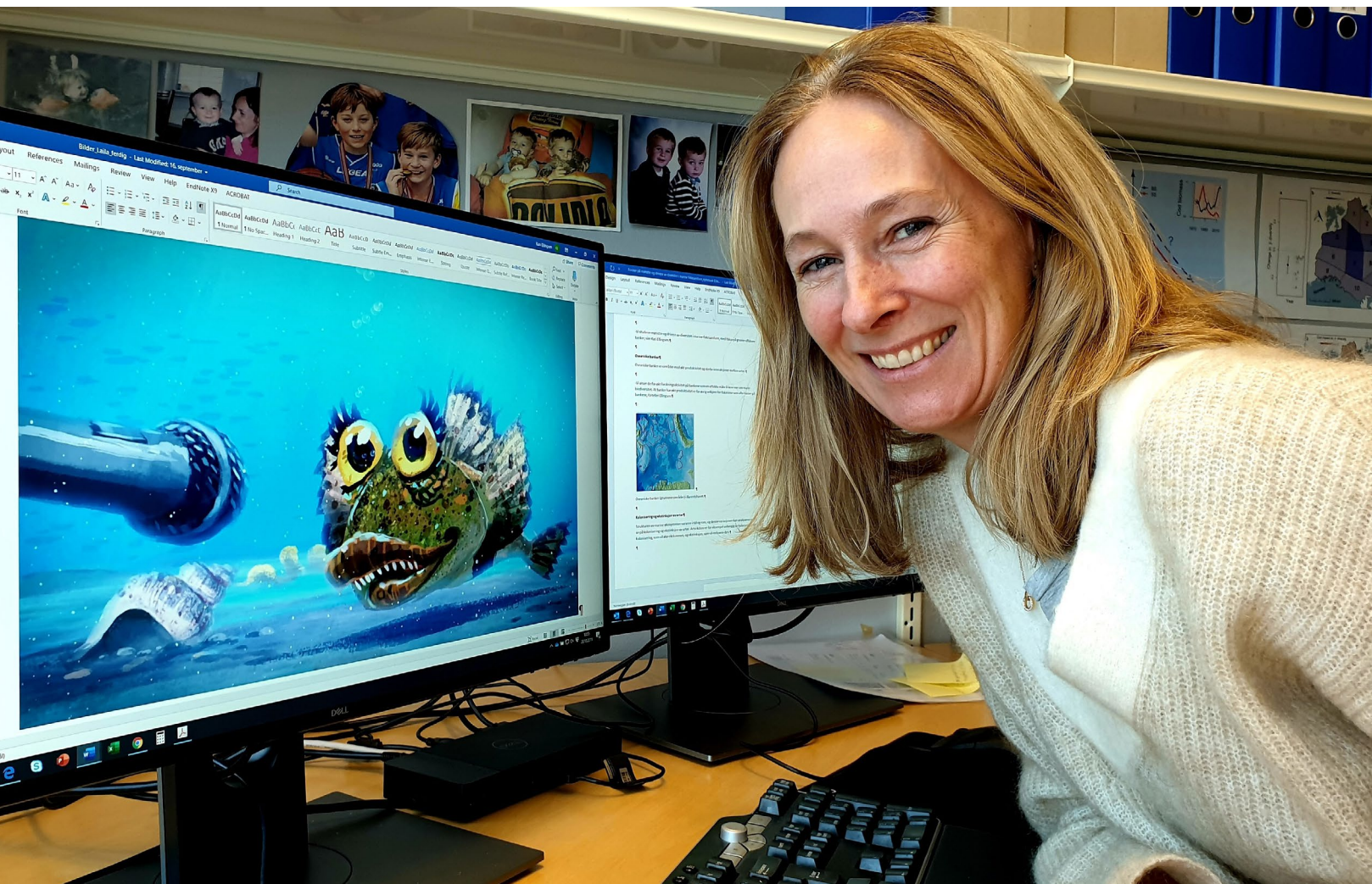
Together with a team of twenty models, stylists and technicians, the three focused on how ordinary citizens have adapted to climatic and environmental changes in the 225 years since Tromsø became a city. The events venue Storgata Camping was packed and the response to the show was fantastic. The performance, produced by the Fram Centre, was one of 400 events held around Europe in connection with Researchers’ Night.

The scheme is a component of the European Union’s Marie Curie actions (the People Programme) aimed at making Europe attractive to researchers by promoting research careers and research communities in Europe. The events target the general public by offering “edutainment” activities, with the objective of increasing people’s knowledge in an entertaining way.

### A LITTLE FISH TELLS A BIG STORY

Speaking through a little fish named Laila, researchers explain their focus on fishing banks.

The tiny sculpin Laila is the star of a new animated film made by the Tromsø-based company Fabeljord. She explains why it is important to know more about the major fishing banks in the north. The film, entitled “My Bank”, was released in October, in Norwegian and English.



Kari Ellingsen was one of the people who came up with the idea of an animated film about Laila, the sculpin. The two-minute film premiered in autumn 2019.

*Photo: Helge M Markusson / Fram Centre*

The idea of making the film was conceived by Kari Ellingsen in the Norwegian Institute for Natural Research (NINA) at the Fram Centre in Tromsø and Ken Frank at the Bedford Institute of Oceanography in Canada. With it, they hoped to reach a broader and - especially - a younger audience. People from NINA and Fabelfjord teamed up to develop a screenplay in which Laila demanded more and more space.

“It’s been a lot of fun being involved in creating an animated film. It has also proved very instructive, because the filmmakers have been good at simplifying and presenting what is really a much more complicated story,” says Kari Ellingsen.

Ellingsen is a senior researcher and leader of the project DRIVEBANKS, funded by MARINFORSK and the Research Council of Norway.

“There’s still a lot we don’t know about fishing banks. We know that the fishing banks are shallow seas where the currents provide good conditions for plankton growth, increasing productivity and supporting rich fish populations. For this reason, fishing banks are also very attractive for fisheries.

“I feel it’s important to reach an audience that isn’t just researchers. Children and young people are eager to protect our natural environment. It’s important for them to be well-informed about what’s going on beneath the surface of the sea and what influences the marine environment,” says Kari Ellingsen.





Kirsti Blom and researcher Rolf Anker Ims presented their children's book about the lemming at Stakkevollan School in Tromsø in December.

*Photo: Helge M Markusson / Fram Centre*

### A LITTLE ANIMAL ACCOMPLISHES A LOT

A pint-size animal with a supersize impact finally it has its own book. Author Kirsti Blom and researcher Rolf Anker Ims, UiT The Arctic University of Norway have written about the lemming.

“Lemen” (The Lemming) is a book for children aged eight to ten. It takes a close look at the most important aspects of the lemming's ecology: its life history; environmental adaptations; what drives the lemming's lifecycle; its role in the ecosystem; and what effects climate change might have. The book has illustrations by some of Norway's best wildlife photographers and presents several “fun facts” and myths about the lemming. It also describes some of the research that has been done on this key species of the Arctic tundra.

Together with researchers from institutions at the Fram Centre, publishing house Cappelen Damm has released 11 books that address various aspects of Arctic nature and research. All of them are suitable for young readers.

This is the sixth book produced in collaboration between the Fram Centre, its researchers, Kirsti Blom, and the publisher. ■



Linda Hanssen from NILU – Norwegian Institute for Air Research (front), Pernilla Carlsson, Norwegian Institute for Water Research (right) and Unni Mette Nordang from the Centre for the Ocean and the Arctic during “The Great Arctic Fashion Show”. *Photo: Sverre Simonsen*

# Projects in the Fram Centre Flagships for 2019

## MIKON

PROJECT TITLE	LEAD INSTITUTE AND FRAM CENTRE PARTNERS	PROJECT LEADER	EMAIL
Current and future vulnerability of Arctic-breeding seabirds to anthropogenic stressors	NINA, NPI, UiT	Arnaud Tarroux	arnaud.tarroux@nina.no
Indigenous-industry governance interactions in the Arctic. Environmental impacts and knowledge basis for management (IndGov).	UiT, NIKU	Camilla Brattland	camilla.brattland@uit.no
ESCE - Ecological Status of Coastal Ecosystems in Northern Norway	IMR, NINA, UiT	Per Arneberg	per.arneberg@hi.no
AMINOR	UiT, IMR, MET, NINA, NORCE, NPI	Sandra Hamel	sandra.hamel@uit.no
Oil Spill Modelling in Ice Covered Ocean - and environmental consequences (OSMICO II)	MET, APN	Lars Robert Hole	lrh@met.no
How to avoid conflicts between wild and farmed salmonids? Finding good locations for aquaculture.	APN, IMR, UiT	Jenny L.A. Jensen	jen@akvaplan.niva.no
Sensitivity of sexually matured polar cod ( <i>Boreogadus saida</i> ) to the water-soluble fraction of crude oil under low and high food regimes	UiT, APN, Nofima, NPI, SINTEF	Ireen Vieweg	ivi006@uit.no
Toxicity of salmon lice pesticides on a key North-Norwegian marine species, <i>Pandalus borealis</i>	APN, IMR, NPI, NIVA	Gro Harlaug Refseth	Gro.Refseth@akvaplan.niva.no
CurBES - Cumulative impacts of the linear infrastructure associated with industrial development on biodiversity and ecosystem services	UiT, NINA, Nofima	Claire Runge	claire.a.runge@uit.no
Productivity effects in reindeer from changes in human land use – improving snow and vegetation map layers to facilitate sustainable land use.	NINA, UiT	Audun Stien	audun.stien@nina.no
Governing environmental and social aspects of salmon farming in four northern countries (FourSalmon)	Nofima, UiT	Kine Mari Karlsen	kine.karlsen@nofima.no
A Traditional Ecological Knowledge Database for Planning and Impact Assessments (TRACE)	NIKU, UiT	Sanne Bech Holmgaard	sanne.holmgaard@niku.no

## Terrestrial

PROJECT TITLE	LEAD INSTITUTE AND FRAM CENTRE PARTNERS	PROJECT LEADER	EMAIL
Pioneering pests: revealing the potential of the range-expanding winter moth to establish itself in low-arctic willow shrub tundra	UiT, NINA	Ole Petter Laksformso Vindstad	ole.p.vindstad@uit.no
ECOGEN - Ecosystem change and species persistence over time: a genome-based approach	UiT, NIBIO	Inger Greve Alsos	inger.g.alsos@uit.no
Health and infectious diseases in semi-domesticated reindeer in a changing climate	UiT, NINA, NORCE, VET	Morten Tryland	morten.tryland@uit.no
The Lemming (book)	UiT	Rolf A. Ims	rolf.ims@uit.no
Pacific salmon effects on terrestrial ecosystem Structure and Services (PASS)	APN, NINA	Guttorm Christensen	guttorm.christensen@ akvaplan.niva.no
Summer's End- influence of snowmelt on the timing of arctic plant phenology and senescence	UiT, NINA, NORCE	Elisabeth J. Cooper	ejcnipr@gmail.com
Socio-ecologic modelling of reindeer population dynamics at multiple spatial scales using a Structural Equation Modelling approach	NINA, NIKU, NMBU	Bård-Jørgen Bårdsen	bjb@nina.no
Cooperative solutions to common problems—the siida system in Saami reindeer husbandry	NIKU, NINA	Marius Warg Næss	marius.naess@niku.no
ReinCSI - Reindeer herding adaptability to climate sensitive infections in Nenetsia and Sapmi	NIKU, NINA, NORCE, UiT	Alma Thuestad	alma.thuestad@niku.no
Sustainable management of renewable resources in a changing environment: an integrated approach across ecosystems (SUSTAIN)	UiT, NINA, NPI	John-André Henden	john-andre.henden@uit.no
EcoShift - Scenarios for linking biodiversity, ecosystem services and adaptive actions.	UiT, NINA	Vera Helene Hausner	vera.hausner@uit.no
The European Goose Management Platform; Coordinating the Agriculture Task Force	NINA	Ingunn Tombre	ingunn.tombre@nina.no
COAT – Climate-ecological Observatory for Arctic Tundra	UiT, MET, NINA, NPI, UNIS	Rolf A. Ims	rolf.ims@uit.no
Frame-by-frame: a new approach for monitoring plant-pollinator interactions by time lapse photography	NINA, UiT	Jane Uhd Jepsen	jane.jepsen@nina.no
Yamal EcoSystem (YaES) - Collaboration for monitoring of climate related ecosystem change on Yamal, Russia	UiT, NINA, NPI	Dorothee Ehrich	dorothee.ehrich@uit.no
Satellite and calibration/validation data in detecting seasonal changes - adapting machine learning techniques	NORCE, NINA, UiT	Stein Rune Karlsen	stein-rune.karlsen@NORCE.no
AMINOR	UiT, IMR, MET, NINA, NORCE, NPI	Sandra Hamel	sandra.hamel@uit.no

## Hazardous substances

PROJECT TITLE	LEAD INSTITUTE AND FRAM CENTRE PARTNERS	PROJECT LEADER	EMAIL
Atmospheric inputs of organic contaminants of emerging concern to the Arctic and possible implications for ecosystem exposures	NILU, APN	Ingjerd S. Krogseth	isk@nilu.no
Development, evaluation, and application of a bioaccumulation model for organic contaminants in Arctic seabirds	NILU, APN, NINA, NPI	Ingjerd S. Krogseth	isk@nilu.no
POPs adsorbing to Marine plastic litter in the Arctic marine environment acting as a new vector of exposure; expanding PLASTOX to the North (PLASTOX-NORTH); year 2	NILU, SINTEF, UiT	Dorte Herzke	dhe@nilu.no
Impacts of environmental contaminants and natural stressors on northern raptors: RAPTOR	NINA, NILU, UiT	Jan Ove Bustnes	Jan.Bustnes@nina.no
Multi-stress relationships in seabird populations: interactions between natural stressors and environmental contaminants	NINA, APN, NILU, NPI, UiT	Jan Ove Bustnes	Jan.Bustnes@nina.no
Giants of the ocean – affected by anthropogenic pollutants?	NPI, APN, NILU	Heli Routti	heli.routti@npolar.no
Microplastics from artificial sports pitches: composition, degradation and biological interactions (MARS)	NILU, APN, IMR, SINTEF	Dorte Herzke, Claudia Halsband	dorte.herzke@nilu.no
ARctic CHarr Super Male quest (ARCHAiSM)	NIVA, APN, UiT	Marc Anglès d'Auriac	mad@niva.no
Urban development, shipping and tourism impacts on the release of environmental contaminants in Tromsø. Investigation of cocktail effects from wastewater effluents on marine ecosystem using bivalves as sentinel species	APN, NILU, UiT, NIVA	Perrine Geraudie	pge@akvaplan.niva.no
Evaluating the significance of spatial variability and body mass index (BMI) for human concentrations of persistent organic pollutants (POPs) in northern areas	NILU/UiT, IMR	Therese Haugdahl Nøst	thn@nilu.no
Screening for Emerging Arctic health Risks to Circumpolar Human populations (SEARCH)	NILU, APN, NPI	Nicholas A. Warner	nicholas.warner@nilu.no
An Arctic risk governance regime for multiple stressors: the case of interaction between climate change and hazardous chemicals (ARIGO)	NIVA, APN, CICERO	Marianne Karlsson	marianne.karlsson@niva.no
AMINOR	UiT, IMR, MET, NINA, NORCE, NPI	Sandra Hamel	sandra.hamel@uit.no

## Fjord and Coast

PROJECT TITLE	LEAD INSTITUTE AND FRAM CENTRE PARTNERS	PROJECT LEADER	EMAIL
Impact of massive Winter Herring Abundances on the Kaldfjorden Environment (WHALE)	IMR, APN, UiT	Angelika Renner	angelika.renner@hi.no
The new generation of <i>Calanus finmarchicus</i> : estimating population recruitment from egg production rates and gonad stage analysis off northern Norway (GONAD)	APN, UiT	Claudia Halsband	clh@akvaplan.niva.no
Multidecadal variations in ocean climate, individual fish growth and population demography revealed by redfish otoliths	APN, IMR	Hector Andrade	hector.andrade@akvaplan.niva.no
Marine snow, pelagic–benthic coupling and the impact of the harpacticoid copepod <i>Microsetella norvegica</i> , and other agents in a high-latitude fjord (MICROSNOW)	UiT, IMR	Camilla Svensen	camilla.svensen@uit.no
CrabPOP – Effects of crab population increase and range expansion on north Norwegian coastal ecosystems	NIVA, APN, IMR	Camilla With Fagerli	cwf@niva.no
Drivers of fish extinction and colonization on oceanic banks (DRIVEBANKS): adding social science and communication with management to ecology and oceanography	NINA, IMR, NPI, UiT	Kari Elsa Ellingsen	kari.ellingsen@nina.no
The quest for the pole: Are southern species already capable of invading the Barents Sea?	UiT, APN, IMR	Raphaelle Descoteaux	raphaelle.descoteaux@uit.no
Fjordic Freshwater Fluxes	UiT, NPI, UNIS	Finlo Cottier	finlo.cottier@sams.ac.uk
Planning for coastal climate change COASTCHANGE	UiT, IMR, Nofima	Claire Armstrong	claire.armstrong@uit.no
Arctic harmful algae biosensor – continuation	APN, UiT	Lionel Camus	lca@akvaplan.niva.no
Urban kittiwakes – human/kittiwake co-existence in urban space	NINA, NIKU, Polaria	Tone Kristin Reiertsen	tone.reiertsen@nina.no
Freshwater inputs to Svalbard's coastal waters: Fluxes, fate, and implications for coastal ecosystems (FreshFate)	NIVA, APN, UNIS, UiT	Amanda Poste	amanda.poste@niva.no
Seabird habitat use and migration strategies	NINA, APN, NPI, UiT	Børge Moe	borge.moe@nina.no

# Arctic Ocean

PROJECT TITLE	LEAD INSTITUTE AND FRAM CENTRE PARTNERS	PROJECT LEADER	EMAIL
Automised Large-scale Sea Ice Mapping (ALSIM)	UiT, MET, NPI	Torbjørn Eltoft	torbjorn.eltoft@uit.no
Long-term modelling and simulation of vessel icing in the Arctic Ocean using high resolution reanalysis data: Climatology and risk analysis.	SINTEF, MET, UiT	Truls Bakkejord Ræder	truls.rader@SINTEF.no
Arctic shipping trends 2013–2018 deduced from data in the marine traffic tool "Havbase"	Nofima, UiT	Eirik Mikkelsen	eirik.mikkelsen@nofima.no
Information systems in the Arctic Ocean: Drivers, architecture, and effects on the development of marine economic activities (ArcticInfo)	UiT, MET	Maaike Knol	maaike.knol@uit.no
Deploying Floating Nuclear Power Plants in the Arctic: Legal and Regulatory Gaps and Challenges (Arctic FNPPs)	UiT, NCA, DSA	Maria M. das Neves	maria.m.neves@uit.no
Assessing the implications of a global treaty on marine biodiversity in areas beyond national jurisdiction for ecosystem-based governance in the Arctic Ocean (ARCTIC_BBNJ II)	UiT, IMR	Vito De Lucia	vito.delucia@uit.no
Processes governing variable Arctic sea ice - the Barents Sea hotspot (ICEHOT)	IMR, MET, UNIS	Vidar S. Lien	vidar.lien@hi.no
Assessment of ecosystem vulnerability and functioning in ice-affected waters (ICEEVA)	IMR, APN, UNIS, UiT	Lis Lindal Jørgensen	lis.lindal.joergensen@imr.no
Mesoscale physical and biogeochemical modeling of the ocean and sea-ice in the Arctic Ocean	NPI, APN, IMR	Pedro Duarte	Pedro.Duarte@npolar.no
Barents Sea harp seals in a changing Arctic	IMR, NPI, UiT	Kjell Tormod Nilssen	kjelltn@hi.no
Long-term variability and trends in the Atlantic Water inflow region (A-TWAIN)	NPI, IMR, UiT	Paul A. Dodd	paul.dodd@npolar.no
TRIMODAL: Using Tracers, Atmospheric Indices and Model Output to explain changes in the Arctic Ocean Inflow and Outflow through Fram Strait	NPI, APN, DSA	Paul A. Dodd	paul.dodd@npolar.no
Mesoscale modeling of Ice, Ocean and Ecology of the Arctic Ocean	APN, IMR, MET, NPI	Hans Kristian Djuve	hkd@akvaplan.niva.no
Ice-Free Arctic Ocean: Dead end or new opportunities for biodiversity and habitat Expansion (FADE)	UNIS, NPI, UiT	Janne E. Søreide	janne.soreide@unis.no

## ABBREVIATIONS

APN: Akvaplan-niva AS

CICERO: Center for International Climate Research

DSA: Norwegian Radiation and Nuclear Safety Authority

IMR: Institute of Marine Research

MET: The Norwegian Meteorological Institute

NIBIO: The Norwegian Institute of Bioeconomy Research

NINA: Norwegian Institute for Nature Research

NIKU: The Norwegian Institute for Cultural Heritage Research

NILU: Norwegian Institute for Air Research

NIVA: Norwegian Institute for Water Research

Nofima: The Norwegian Institute of Food, Fisheries and Aquaculture Research

NORCE: Norwegian Research Centre AS

NPI: Norwegian Polar Institute

SINTEF: The Company for Industrial and Technological Research

UiT: UiT The Arctic University of Norway

UNIS: The University Centre in Svalbard

VET: Norwegian Veterinary Institute

# Ocean Acidification

PROJECT TITLE	LEAD INSTITUTE(S) AND FRAM CENTRE PARTNERS	PROJECT LEADER(S)	EMAIL
OA WP1: Ocean acidification state and drivers in Arctic waters (OA-State/OA-Drivers)	NPI&IMR, NIVA	Agneta Fransson, Melissa Chierici	agneta.fransson@npolar.no
OA WP2: Sensitivity of Marine Biota to the Acidification of northern waters and its effects on marine ecosystems	IMR&NPI, APN, NINA, NIVA	Sam Rastrick, Haakon Hop	sam.rastrick@hi.no
OA WP2-1: The effect of OA on gametes and vulnerable life stages	NINA&APN&IMR, UNIS	Johanna Järnegren, Claudia Halsband, Howard Browman	johanna.jarnegren@nina.no
OA WP2-2: The effect of natural temporal and spatial variations in multiple OA drivers (pCO <sub>2</sub> , salinity and temperature) on the physiology and skeletal properties of benthic and planktonic organisms.	NPI&IMR, NIVA	Haakon Hop, Sam Rastrick	haakon.hop@npolar.no
OA WP2-3: Capacity for adaptation in Arctic invertebrates to multiple OA drivers (pCO <sub>2</sub> , salinity and temperature).	IMR&NPI	Howard Browman, Sam Rastrick	howard.browman@hi.no
OA WP3: Understanding and Predicting the acidification of northern waters and its impacts on marine ecosystems and biogeochemistry (TRUMP)	NIVA&IMR, NPI	Philip Wallhead, Solfrid Hjøllø	philip.wallhead@niva.no
OA WP4: Risk governance and ocean acidification: understanding the role of uncertainty	NIVA, NORCE	Marianne Karlsson	marianne.karlsson@niva.no

## FRAM – High North Research Centre for Climate and the Environment

The Fram Centre consists of scientists from 21 institutions involved in interdisciplinary research and outreach in the fields of natural science, technology and social sciences.


### Members 2020

- Akvaplan-niva
- CICERO Centre for International Climate Research
- Institute of Marine Research
- National Coastal Administration
- National Veterinary Institute
- NGU – The Geological Survey of Norway
- NILU – Norwegian Institute for Air Research
- NINA – Norwegian Institute for Nature Research

- NIKU – Norwegian Institute for Cultural Heritage Research
- Nofima – The Norwegian Institute of Food, Fisheries and Aquaculture Research
- NORCE
- Norwegian Meteorological Institute
- Norwegian Polar Institute
- Norwegian Institute for Bioeconomy Research
- Norwegian Institute for Water Research
- Norwegian Mapping Authority
- Norwegian Radiation and Nuclear Safety Authority
- SINTEF Group
- UNIS – The University Centre in Svalbard
- UiT – The Arctic University of Norway
- Associated member: Polaria

For contacts and further information, visit:

[framcentre.com](http://framcentre.com)



*FRAM - High North Research Centre on Climate and the Environment* contributes to Norway's sound management of the environment and natural resources in the north - and we aim at excellence in said management. With scientific research as our foundation, we communicate knowledge to management authorities, the business communities, and the general public.



**Fram Centre**  
Framsenteret, POB 6606 Langnes  
N - 9296 Tromsø

**Phone:** +47 77 75 02 00

**Fax:** +47 77 75 02 01

**E-mail:** [post@framsenteret.no](mailto:post@framsenteret.no)

[www.framsenteret.no](http://www.framsenteret.no)

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