FRAM CENTRE

FRAM FORUM 2018

CONTENTS

FRAM Forum is published once a year on behalf of FRAM – the High North Research Centre for Climate and the Environment. Its aim is to inform the general public about the wide range of activities that take place within the Fram Centre. It is available free of charge to any and all who are interested in topics related to climate, environment, and people in the High North.

Editor
Janet Holmén
Freelance editor
// alchemia@online.no

Project leader
Helge M. Markusson
Outreach Coordinator
Fram Centre
// helge.markusson@framsenteret.no

Editorial committee

Cathrine Henaug
NINA Norwegian Institute for Nature Research
// cathrine.henaug@nina.no

Elin Vinje Jenssen
Norwegian Polar Institute
// elin.vinje.jenssen@npolar.no

Eva Therese Jenssen
University Centre in Svalbard
// eva.therese.jenssen@unis.no

Christine F. Solbakken
NILU – Norwegian Institute for Air Research
// christine.solbakken@nilu.no

Randi M. Solhaug
UiT The Arctic University of Norway
// randi.solhaug@uit.no

Gunnar Sætra
Institute of Marine Research
// gunnar.saetra@imr.no

Cover photo
Landsat 8 image of Hopen, Svalbard // Image: U.S. Geological Survey

Layout
TANK Design AS
www.tank.no

Printer
Lundblad Media AS
Print run: 1000 copies

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

www.framsenteret.no
post@framsenteret.no
Phone: +47-7775 0200

AS BOUNDLESS AS THE SEA?

Throughout human history, the ocean has symbolised vastness beyond comprehension: distant horizons and unfathomable depths. The ocean was infinite. It was inconceivable that so broad an expanse could be vulnerable to the actions of mere humans. So the ocean became a handy trash receptacle. Nobody worried when ships at sea jettisoned food scraps, fish entrails, human waste. They assumed that anything dumped overboard would "feed the fishes", that the bottomless sea would swallow up whatever the mariners no longer wanted.

Although that may once have been true, the human population is considerably larger now. Modern society produces copious amounts of trash. No doubt much of the waste that flows into the ocean is still eaten by sea creatures. But they also eat waste that is toxic or indigestible. Maybe the waste will kill them, maybe not. Either way, foreign compounds enter the food chain. How much ends up in the fish on your plate?

Plastic waste is a particularly urgent problem. Plastic litters shorelines from pole to pole. It accumulates in gyres at the centre of the major oceans; fragments of plastic sink through the water column and lie scattered on seabeds all over the world.

Human activities also have indirect effects on the oceans. By burning fossil fuel, we change the composition of the atmosphere. Air is in constant exchange with seawater. As atmospheric carbon dioxide levels increase, more CO_2 enters the sea, where it decreases the water's pH, potentially threating many marine organisms. In addition, greenhouse gasses like CO_2 trap heat in the lower atmosphere. When the air gets warmer, so does the ocean's surface water, and storms become more likely. Both storms and warm water reduce the amount of sea ice.

Alarmingly, recent reports show that ocean temperatures have risen not only at the surface, but also at depth, which may alter ocean circulation patterns in unpredictable ways. These physical changes in the ocean are prompting other changes. Fish and plankton populations move to new habitats. Organisms from ice-algae to polar bears struggle when sea ice disappears, while humans (ever the most opportunistic of species) seek out new trade routes.

Clearly, although the sea is vast, humans are by no means powerless to affect it. As the world grows hungrier and more crowded, perhaps we will need to shift our food production from grassy green pastures to watery blue ones. But if we want the ocean to be a sustainable larder, we need to understand the marine environment: what is its current state, what processes control its function, how might it react to various types of perturbations, and what can we do to protect its health - and our own interests.

Understanding anything as complex as the sea often requires a multidisciplinary approach. Fortunately, that is one of the Fram Centre's strengths. From its inception, FRAM - High North Research Centre for Climate and the Environment was designed to foster collaboration between researchers in different fields. The success of that strategy is clear from the fact that nearly all the projects in the Fram Centre Flagships involve several institutions.

The Fram Centre's ability to transcend disciplinary boundaries is set to increase further this year, when we expand into the new wing south of the original building. The Tromsø branch of the Institute of Marine Research - a charter member of the Fram Centre family - has already joined us under the same roof. Other organisations will soon follow. Several Fram Centre institutions will benefit from additional floor space and new or upgraded laboratory facilities.

Last but not least, we hope the glassed-in atrium between the old and new wings of the Fram Centre will become a lively arena for communication - not just between research disciplines, but also between researchers and the public. Do you wonder if the fish on your plate is safe to eat? Come talk to us! We're just as eager for answers as you are.

Janet Holmén, Editor

Picture of the year

Recent years have seen a massive increase in public awareness of the problem of plastic in the sea. This has prompted people to organise excursions to clear away some of the plastic waste that washes ashore along the Norwegian coast. This picture was taken on Vengsøya west of Tromsø in May 2017. The photographer, Bo Eide, works as a climate and environmental advisor for the Municipality of Tromsø. In this capacity, he coordinates the clean-up efforts of Ren Kyst (Clean Coast). When he came across this beat-up globe on the beach, he felt obliged to take a picture. It speaks more eloquently than any words.

Photo: Bo Eide


ATLANTIC OCEAN

Camilla Næss

Meet the puffin man

The Røst archipelago is famous for its dried cod and large seabird colonies. Back in the late 1970s, it was the summer residence of 1.5 million pairs of breeding puffins. Today more than three quarters are gone. Tycho Anker-Nilssen has dedicated his career to solving the mysterious death of these bird cliffs.

He arrives in spring. Rather, *he is* a sign of spring, as reliable as the migrating seabirds he studies. When he arrives in the first week of May, dropping by the local store to take in supplies and catching up on the latest news, the islanders of Røst know that puffin season has begun.

ATLANTIC PUFFIN HOTSPOT

With its extreme location and distinctive topography, Røst is a hotspot for birdwatching. Here you find one of the world's largest breeding colonies of Atlantic puffin (*Fratercula arctica*) spread across 17 of the allegedly 365 islands in this offshore municipality. The birds spend winter out at sea, and return to the colony in April.

Shortly after, they are joined by Tycho Anker-Nilssen, senior research scientist at the Norwegian Institute for Nature Research, who monitors their numbers and breeding performance. Gaps in the data series would be detrimental, so the fieldwork at Hernyken has been one of his main priorities. Over the past 37 years, he hasn't missed a single summer.

He hasn't missed much else either, for that matter. Being married and having two teenagers from the second clutch - in addition to a now 30-year-old son from the first - he still leads a rich social life. On top of that, he has published hundreds of scientific papers and reports, a great achievement in its own right. However, unlike many scientists, he didn't stop there. Driven by curiosity he has played a crucial role in advancing seabird research and conservation both in Norway and internationally. To put it succinctly, he has been a major force in telling people why seabirds are relevant.

> "Norwegian seabird research isn't just a gloomy report of seabirds facing extinction, but also a long tale of the dedicated people who work tirelessly to reveal the underlying reasons, and continue the quest to find out how we can reverse the negative trends. I'm proud to be part of this tradition, and to pass on the story."

A YOUNG ENVIRONMENTALIST

Practically raised with a bird in his hand, Tycho marked out his course early. His father would scatter tons of sunflower seeds to feed overwintering birds. Tycho's childhood summers were all about catching the largest fish and collecting feathers and birds' eggs in the neighbourhood woods - until the boys realised what a crime they had committed.

Tycho Anker-Nilssen is always surrounded by puffins. There are puffins (stuffed) in his office, portrayed on his coffee mug, his t-shirts, his favourite tie, and a wide variety of pins he has made or been given over the years. But believe it or not, him getting the office at NINA with his own puffin portrait on the door was purely coincidental...
Photo: Anne Olga Syverhuset

Tycho with a bird's-eye view of Røst from the top of Hernyken. *Photo: Ole Wiggo Røstad*

> "We really saw no reason for any serious concern for nature. The prevailing idea at the time was that nature was a pantry, and the oceans contained an inexhaustible supply. When televisions became ubiquitous, and the news anchors reported on the collapse of the Atlantic herring our perception changed."

Instead of stealing eggs, the awakening environmentalist chose to study the natural sciences and set out to save the birds.

At the University of Oslo, he became one of those eternal students so typical of that time, the ones some thought would never make anything of their lives.

But Tycho, curious by nature and a dedicated collector (of bird ringing statistics, of ecological insight, of single malt whisky - to mention a few) also collected valuable experience whenever he added another item to his collections. Collecting makes him tick.

During his biology studies, he spent 565 days ringing birds and investigating box-nesting great tits at an inland field station just outside Oslo. In those years, he also co-managed the Oslo Bird Ringing Centre together with a group of friends. After all, someone had to do it and being students in the 1970s, they had the opportunity.

Tycho ready to release 21 newly captured and ringed puffins at Hernyken on 11 July 1983. At this time, the Røst project depended on voluntary, unpaid work and donations – stimulating creativity. The beer crate he is holding was beached flotsam from Aberdeen; the tubes are old but well-cleaned oilcans, making biting and scratching puffins easier to handle.
Photo: Ole Wiggo Røstad

UNIQUE TIME SERIES

When Tycho first set foot on Røst in 1981, his predecessors had already been collecting data there for two decades. They had initiated what is now one of the longest and most comprehensive seabird time-series ever compiled, and it is fair to say that the field station on the remote island of Hernyken is where Norwegian seabird research earned its wings.

In the early days, devoted individuals drove the research forward, although lacking a long-term plan. Svein Myrberget, one of the pioneers, initiated the puffin studies when he moved his research to Røst in 1964. On Hernyken, the puffins nest in burrows on grassy slopes, which makes them easier to study than on the rocky island of Lovunden.

When Gunnar Lid succeeded Myrberget in 1970, the research took on a more organised character. By the end of the decade, the first national seabird project was launched with funding from the Norwegian Directorate for Wildlife and Freshwater Fish. When Lid tragically drowned during fieldwork in 1983, Tycho was his natural successor to carry the project forward.

Over the years to come, Tycho and his colleagues proved a close relationship between food and chick mortality, and the herring's role became apparent.

> "The continued decline in populations of puffins and several other cliff-breeding species had been a concern since the monitoring started, but we knew little about the underlying mechanisms. As we added years and data to the time series, alongside various shorter-term research projects, we were able to add missing pieces to this puzzle."

Photos: Tor Kvam (1975) / Tycho Anker-Nilssen (2009)

The primitive cabin depicted above served as bedroom, kitchen and working space for the scientists for 45 years. In 2009 it was finally replaced by a modern, fully isolated cabin (facing page). Building only in their spare time, the field team needed six summers to complete it, learning as they went and getting better as do-it-yourselfers with each season.

FIELD LIFE AT RØST

On their first trip in early May, Tycho and his crew start collecting data and monitor the size of the breeding population. One month later, they return to follow the outcome of breeding in several hundred nests, ringing adult birds, and collecting food samples. August marks the end of the season, when they return for one last stint of fieldwork, ringing chicks before they fledge. In addition, the research team monitors a whole range of other species, tracking the movements of some birds using miniature data loggers. Collecting new knowledge makes fieldwork an exciting experience, week after week, year after year. Decades go by, but new and unexpected things turn up all the time.

> "We don't do this just to understand what's happening on Røst, but to reveal some of the major mechanisms in the interaction between important components of the marine environment along the Norwegian coast. The more we learn, the better we

understand our observations and which questions it is important to answer at any given time. Continuing the seabird research and monitoring on Røst for the benefit of present and future society isn't just laborious work. It's a professionally challenging and exciting task."

But life at the field station isn't all about work. Living close together for weeks in a small damp cabin, often under harsh weather conditions, challenges people's social skills and doesn't suit everyone. For those who fit in, however, fieldwork adds new dimensions to their personalities. Long-lasting friendships, creative cooking skills and handiness are but a few of the many side effects of field life.

THE NEVER-ENDING QUEST FOR KNOWLEDGE

Acknowledged for his work, and an important voice in both local and international forums, people listen when Tycho talks - and believe me, he likes to talk. However, getting people to listen hasn't always been a matter of course.

"That benefit follows age I guess. Breaking through established opinions and bringing new research to the table can be quite a challenge. Take SEAPOP for instance; it took us seven years just to get the programme started."

SEAPOP, a research programme integrating long-term monitoring and mapping of Norwegian seabirds, provides and maintains baseline knowledge about seabirds for an improved management of the marine environment. When the programme was established in 2005, it was a milestone for mapping and monitoring seabirds in Norway, and owes much to Tycho's commitment and persistence.

One of his strengths is his ability to translate new knowledge into practical management - making research relevant to society. He has contributed to

The world's oldest puffin whose age was known for certain also spent its summers on Hernyken until being killed by a raven or falcon at age 41. *Photo: Tycho Anker-Nilssen*

making seabird research an important information source for nature management, and brought the issues into the public debate. At the same time, his own research has helped improve our general understanding of seabird ecology.

In order to predict the future, we must also understand the past. In retrospect, the continuity of the puffin study at Røst has helped advance our knowledge about pelagic seabirds by leaps and bounds, especially when the results are analysed in broader contexts.

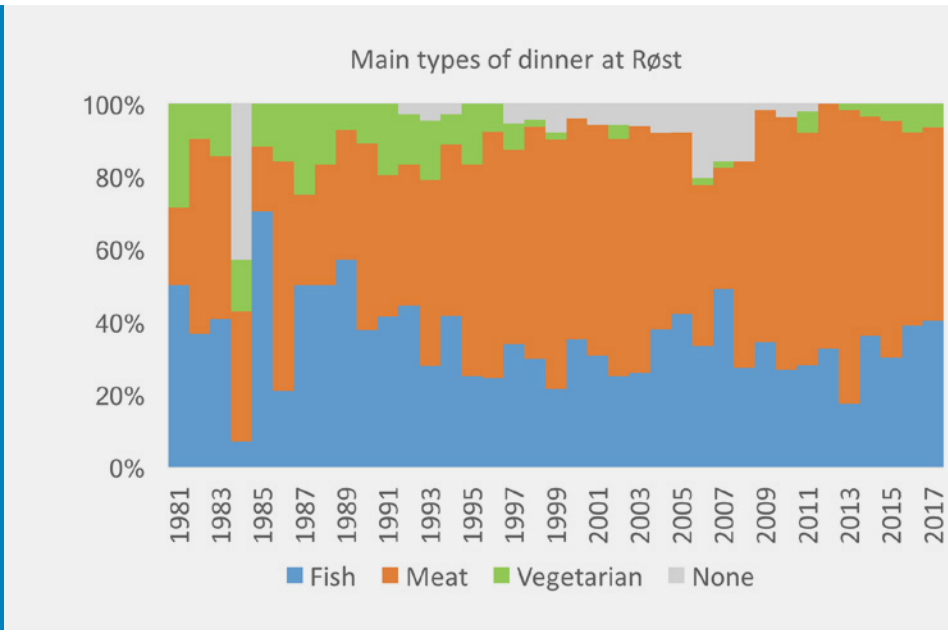
> "This can only be achieved with a multi-disciplinary approach and an extensive cooperation with colleagues across the borders of seas and oceans. New challenges continue to appear and there are still more questions than answers, but our insight into many important issues such as the relative importance of fisheries and climate change has increased substantially."

Seabirds are good indicators of the health of marine ecosystems, not only because of their visibility, colonial breeding and ease of study, but also because they respond early to important changes in the marine environment. This is particularly true for long-lived, fish-eating specialists, which are constantly forced to balance their investment in reproduction against their own chances of survival. Continuing these time series is therefore crucial.

Ecosystems present a complex picture, with delicate balances and cycles. Competition, climate, predators and prey - everything interacts in determining whether a species will thrive or struggle for survival. Seabirds have long generation times, and can live for decades. According to Tycho, a research career is far too short a timespan to uncover the full functioning of these ecosystems, but a career like Tycho's definitely propels us a long way towards understanding and ultimately saving some components of the ecosystem - like the puffin. ■

Greetings from Røst! Røst is the centre for the Lofoten fisheries when spawning cod arrive from the Barents Sea. This spring fishing tradition dates back centuries. During summer, Røst is a favourite among birdwatchers and scientists alike.
Photos on postcard: Rune Kristian Ellingsen, Røst. Photo of postcard: Camilla Næss

A collector's mind. If you ask Tycho what he had for dinner on any given day on any of his field trips to Røst, chances are you will get a detailed, mouth-watering description. All meals are meticulously recorded in his field logs, and presented in graphs in an idle hour.



Plastic litter in Tromsø, northern Norway.
Photo: Bo Eide

Dorte Herzke // NILU – Norwegian Institute for Air Research
Claudia Halsband // Akvaplan-niva

Marine plastic pollution in the Arctic: an emerging research field

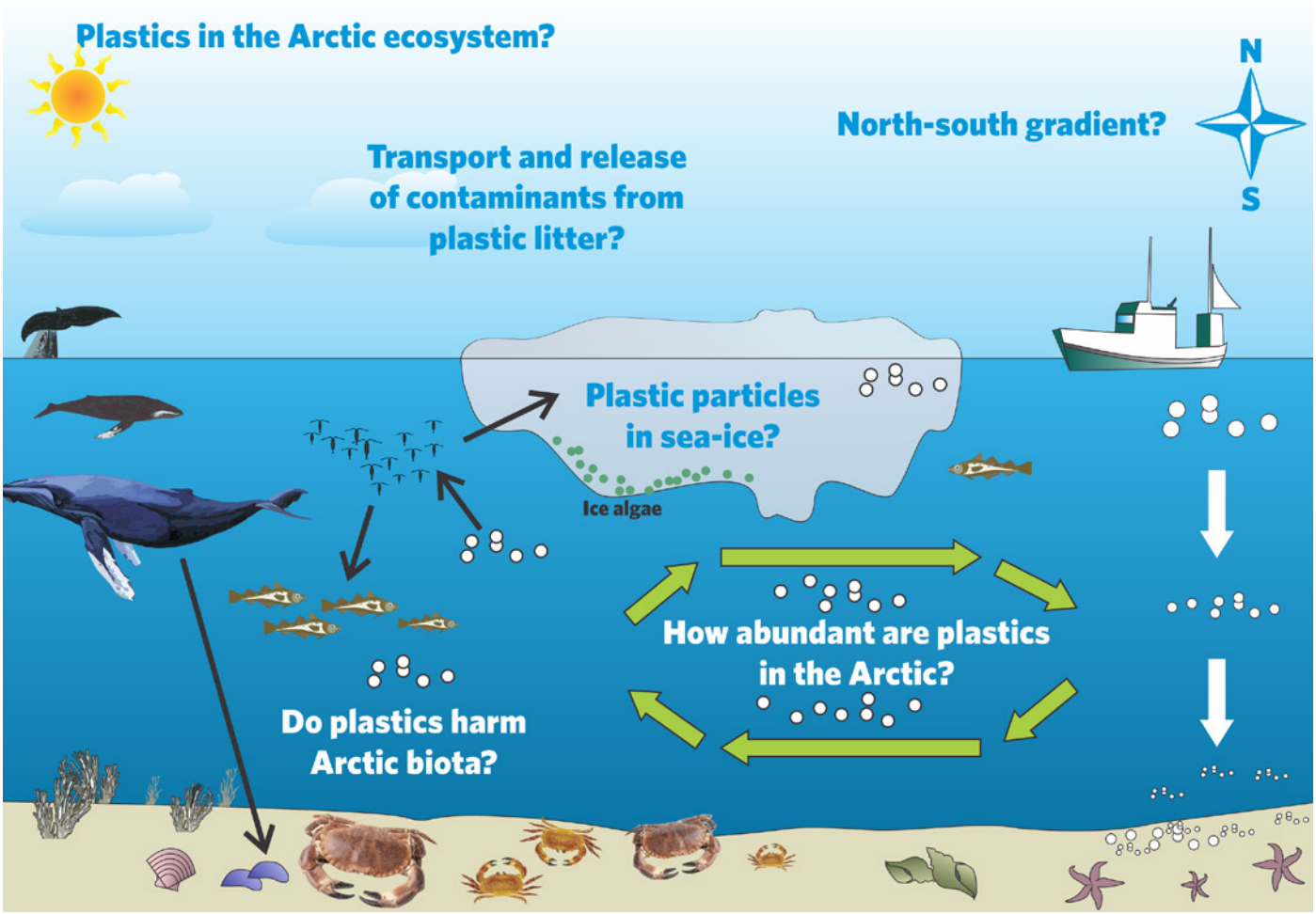
We find marine plastic litter everywhere we look, but we still know far too little about the extent of this problem in Arctic regions.

IN THE LAST FIVE YEARS, a group of Fram Centre researchers have taken on the challenge of filling some of the knowledge gaps about plastic pollution in the High North, as well as pointing out sources that were previously overlooked. These include crumb rubber used in artificial turf and synthetic fibres released to fjords with waste water effluents in arctic settlements.

IN THE BEGINNING...

The geographic distribution of plastic litter, its sources and sinks, and its effects on arctic ecosystems long remained virtually unstudied.

Surprisingly, the scientific community has been ignoring the problem of increasing plastic litter in the world oceans for nearly a quarter century - despite the obvious visual clues left behind on beaches everywhere.



Examples of knowledge gaps about the behaviour, pathways and impacts of plastic litter in the Arctic.

It is clear that significant amounts of plastic litter arrive in the remote regions of the Arctic, but systematic research to map its provenance has begun only recently. The Norwegian Polar Institute (NPI) first reported plastic ingestion by northern fulmars in Svalbard in the mid-1980s. In 2010, the Norwegian Institute for Air Research (NILU) initiated CLEANSEA, an EU project on marine plastic pollution, together with the Norwegian Institute for Water Research (NIVA) and the University of Amsterdam.

JOINING FORCES

Although several individual researchers at Tromsø-based institutes have worked on different aspects of plastic pollution for many years, no concerted effort had been made until 2012. Then, a Fram Incentive project brought interested researchers in the Fram Centre together to gauge interest and expertise in the field.

Since then, the Centre's Hazardous Substances Flagship has awarded more than 2.5 million NOK of funding for research and outreach on plastic litter, leading to a new network of expertise and new insights into the problem in northern and Arctic areas. The research activities cover a broad range of topics, including spatial distribution, and chemical characterisation of plastics and their additives (Institute of Marine Research [IMR], NILU, NPI), understanding sources, pathways and effects of ingestion (Akvaplan-niva, NILU, NIVA, SINTEF), and estimating the socioeconomic consequences of marine plastic pollution (Northern Research Institute [NORUT]). These investigations have led to 8 peer-reviewed publications and 6 reports so far. The results highlight that:

- Plastic pollution is ubiquitous along the Norwegian coast and around Svalbard
- Plastic ingestion by Svalbard fulmars does not decrease northward as would be expected as the distance from human marine impact increases
- The impact of ingested microplastics on the concentrations of persistent organic pollutants in bird tissue is negligible and needs to be considered in the context of background contamination values
- Atlantic cod along the Norwegian coast ingest (micro)plastics
- Arctic zooplankters ingest microplastics in laboratory experiments and prefer "aged" particles over clean ones, because marine microbes form a nutritious biofilm around the plastic
- Microplastics alter the sinking rates of zooplankton faecal pellets, which could reduce the vertical carbon flux in marine systems
- Marine plastic pollution is a circumpolar challenge, already described in the early 1970s, with unknown sources and impacts

INSPIRING INTEREST

Within these projects and with additional financial help from the incentive fund, we work to address the enormous interest of the general public, who seek information about the problems marine plastic pollution can cause.

The most recent example is an exhibition and quiz, funded by the Fram Centre and organised in collaboration between NORUT, NPI, NILU, Akvaplan-niva and Polaria, where the public can learn and then test their knowledge about plastic production, recycling and pollution. At the research fair "FrittFram", activities relating to contaminants, including plastic, are offered every fall by the Municipality of Tromsø, NGOs, and most of the Fram Centre institutions involved in research.

The website http://sustain.no is part of an outreach effort to get young people interested in sustainable development and environmental research. During their annual "Research campaign" for 2017, about 12 500 schoolchildren played almost 600 football matches all over Norway to help investigate how much rubber disappears from soccer fields when the crumb rubber from the artificial grass infill adheres to clothes and shoes ("Sjekk kunstgressbanen"; https://www.miljolare.no/aktiviteter/kunstgress/).

Left: Plastic quiz at Polaria. Right: Research fair.
Photos: Dorte Herzke / NILU – Norwegian Institute for Air Research

COMMUNICATE, COORDINATE – TAKE ACTION!

We still lack reliable data on the extent of microplastics pollution and its ecological impacts through exposure to plastic litter itself or its additives and adsorbed contaminants throughout the Arctic marine ecosystem. Although microplastics have been recognised as an emerging contaminant, e.g. by the Norwegian Environment Agency and the Arctic Monitoring and Assessment Programme, the quest for coordinated research funding required to investigate the global problem of Arctic marine plastics comprehensively proved difficult.

Through direct dialogue between researchers and regulators, we need to communicate how better knowledge and coordinated research will enable policy-makers to develop appropriate measures and action plans to tackle this environmental challenge.

One step towards improving communication with the policy sector was a panel debate at Arctic Frontiers 2018, about what science can provide to tackle the issues of plastic litter and microplastics in the Arctic. The panel highlighted that collaboration across science, policy and industry is urgently needed to produce science-based advice for stakeholders and policy-makers. Among other things, Fridtjof Unander from the Research Council of Norway suggested an "Agenda Plastic 21". ■

Photo: Terje Mortensen / Arctic Frontiers 2018

Panel debate between scientists and policy makers at Arctic Frontiers 2018
Left to right: Ola Elvestuen, Norway's minister of Climate and the Environment, invited speaker Dr. Jenna Jambeck (University of Georgia, USA), Jan Dusik, Principal Adviser for Strategic Engagement for the Arctic and Antarctic at UN Environment, Marit H. Haugseth, Norwegian Fishermen's Association, Fram Centre researcher Dr. Claudia Halsband (Akvaplan-niva), Fridtjof Fossum Unander, head of Energy, Resources and Environment at the Research Council of Norway, and Karoline Andaur, acting secretary general of WWF Norway.

Paul E. Renaud // Akvaplan-niva and University Centre in Svalbard
Martin Biuw and Angelika Renner* // Institute of Marine Research
Karl Øystein Gjelland // Norwegian Institute for Nature Research

Herring impacts on north Norwegian fjord ecosystems

One ordinary day at Christmastime in 2012, Kaldfjorden is illuminated by the lights of an unusually large number of fishing vessels. On land, roads are blocked by hundreds of cars: everyone wants a glimpse of the humpback whales and orcas that have invaded the fjords around Kvaløya. What is going on?

* Also affiliated with UiT The Arctic University of Norway

The small research vessel *Chinga* is used in the weShare and WHALE projects. Here we are tagging a humpback whale in Kaldfjorden.

Photo: Audun Rikardsen / UiT The Arctic University of Norway

Seafloor photograph from the scavenger lander deployment at 170 m depth in Kaldfjorden. Herring bait is attacked by large snails (Buccinidae) and Atlantic cod. Approximately 3 kg of bait was consumed in less than 8 hours. *Photo: Katherine Dunlop and Andrew Sweetman*

Zoe Walker and Ingrid Wiedmann (UiT) recover the CTD and water sampler during autumn sampling. *Photo: A Renner*

These dramatic events were seen already during the winter of 2011-2012 in the fjords in Troms. Fishing vessels arrived in large numbers, tracking huge schools of Norwegian spring-spawning herring on their way from the Barents Sea feeding grounds to spawning areas off western Norway. In fact, there were so many herring that the fjord system was clearly impacted: farmed salmon died from lack of oxygen in the water, and humpbacks and orcas feasted on the huge schools of herring. Locals took to the water in small boats and kayaks, the whale-watching industry picked up, and the fjord suddenly became spectacularly crowded in the middle of the polar night.

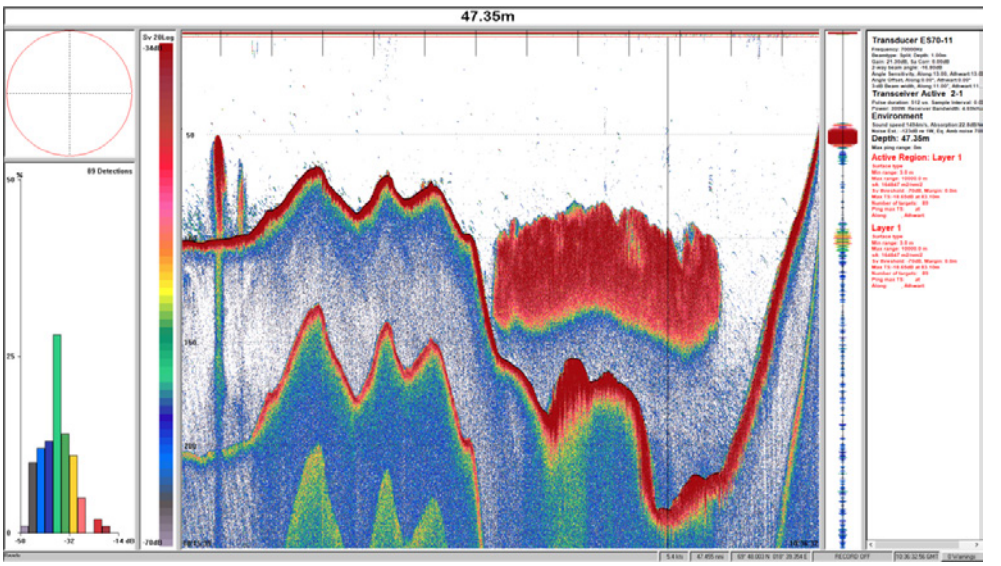
For the marine science community in Tromsø, the herring and whale invasions raised several questions:

- Why are the herring coming into the fjords, and how many herring are there?
- What impact do they have on the fjord ecosystem, from the water column to the seafloor?
- How is society affected, both locally along the fjords, slightly further away in Tromsø, and nationally with respect to the fishing industry?
- And of course, how long will this last?

To answer some of these questions, a group of Fram Centre scientists have developed three projects within the Fjord and Coast Flagship that aim to provide an integrated understanding of the Kaldfjord ecosystem. One project (WHALE) collects baseline hydrographic and water chemistry data during monthly sampling campaigns. Short-term organic flux data are collected using 24-hour sediment trap deployments. In addition, WHALE implements two hydrographic models; predicted circulation patterns are compared and validated with field data from hydrographic surveys and moored current meters. This combination of models and field measurements will enable us to look at water exchange between the fjord and the deeper waters off the shelf and estimate how quickly the fjord waters are renewed. Supplemented with samples taken already in autumn 2016, and oxygen profiles taken during the hydrographic surveys, this study will provide clues as to how herring superabundance affects water chemistry.

The EFFECTS project investigates the fate of organic matter that sinks to the seabed, including herring killed or injured by fishing and predation. We place these results in the context of a larger study of geochemical processes at the seafloor to understand how the appearance of large herring schools affects ecosystem processes in north Norwegian fjords. Scavenging rates on herring carcasses in Kaldfjorden proper were 10-30 times higher than in nearby Vengsøyfjorden. Primary scavengers in Kaldfjorden were large snails and Atlantic cod. Residence time of carcasses on

Screenshot from a hydroacoustic survey from 47 m depth in Kaldfjorden, just outside Skulsfjorden showing herring (the large red and green mass) filling the basin. The seafloor is indicated by the U-shaped dark red line.



the fjord bottom has significant impact on sediment processes and the oxygen content of bottom-water.

The third project, weShare, addresses herring and their predators (including whales and fishing fleets). Frequent hydroacoustic surveys during the herring overwintering season assess their biomass and distribution within the Kaldfjord-Vengsøyfjorden system. We also investigate interactions between herring and their whale predators by using dive recorders and accelerometers attached to the whales. These instruments detect feeding lunges which, when coupled with population sizes, can help us estimate how much herring is consumed by the whales. In addition, humpback and orca migration routes are mapped using either GPS loggers or satellite telemetry, and these data are coupled with photo-identification of individual whales.

Preliminary results suggest that 400-600 humpback whales visit these fjords during a season, and that some individuals remain in the area for 4-6 weeks. We estimate that humpbacks consume approximately 20 000 to 25 000 tonnes of herring within a season. In comparison, fisheries catches during the 2014/2015 season in the Kaldfjorden-Vengsøyfjorden system were approximately 38 000 tonnes. Our initial estimates of the total herring biomass within this fjord system during that season indicate a peak biomass of ~1 500 000 tonnes in mid-December, which represents about 20% of the entire spawning stock of Norwegian spring-spawning herring.

Together, these three projects describe how mass occurrences of herring affect water chemistry, dissolved oxygen levels, and vertical flux of organic matter in Kaldfjorden. We evaluate the various potential fates of herring, from direct predation and fishing loss, to scavenging and decomposition on the seafloor. Companion projects study the socioeconomic impacts of seasonal herring and whale visits to north Norwegian fjords. Thus, we are developing a multi-disciplinary perspective on the effects of herring on a north Norwegian fjord.

After six straight years of herring superabundance in Kaldfjord, no large schools appeared there in late 2017. While this is disappointing for the completion of these projects - not to mention the local tourist and fishing industries - we have compiled enough data to begin to piece together the multi-level effects of herring on the ecosystem, and on the biology of their whale predators. Recent shifts in winter abundances of herring may, in fact, broaden the implications of this research. It appears now that many areas along the coast can experience winter herring invasions. The data gathered here can help predict the impact of these events on fjord ecosystem processes across the fjords of north Norway in general. The results are valuable for managing herring as a biological resource, and for addressing potential synergies and conflicts among industries associated with their presence, informing managers of both threats and benefits of the winter wanderings of this important fish population. ■

Laura Crews and Arild Sundfjord // Norwegian Polar Institute
Jon Albretsen // Institute of Marine Research
Tore Hattermann // Akvaplan-niva and Alfred Wegener Institute

Eddies transport Atlantic heat into the deep Arctic Ocean

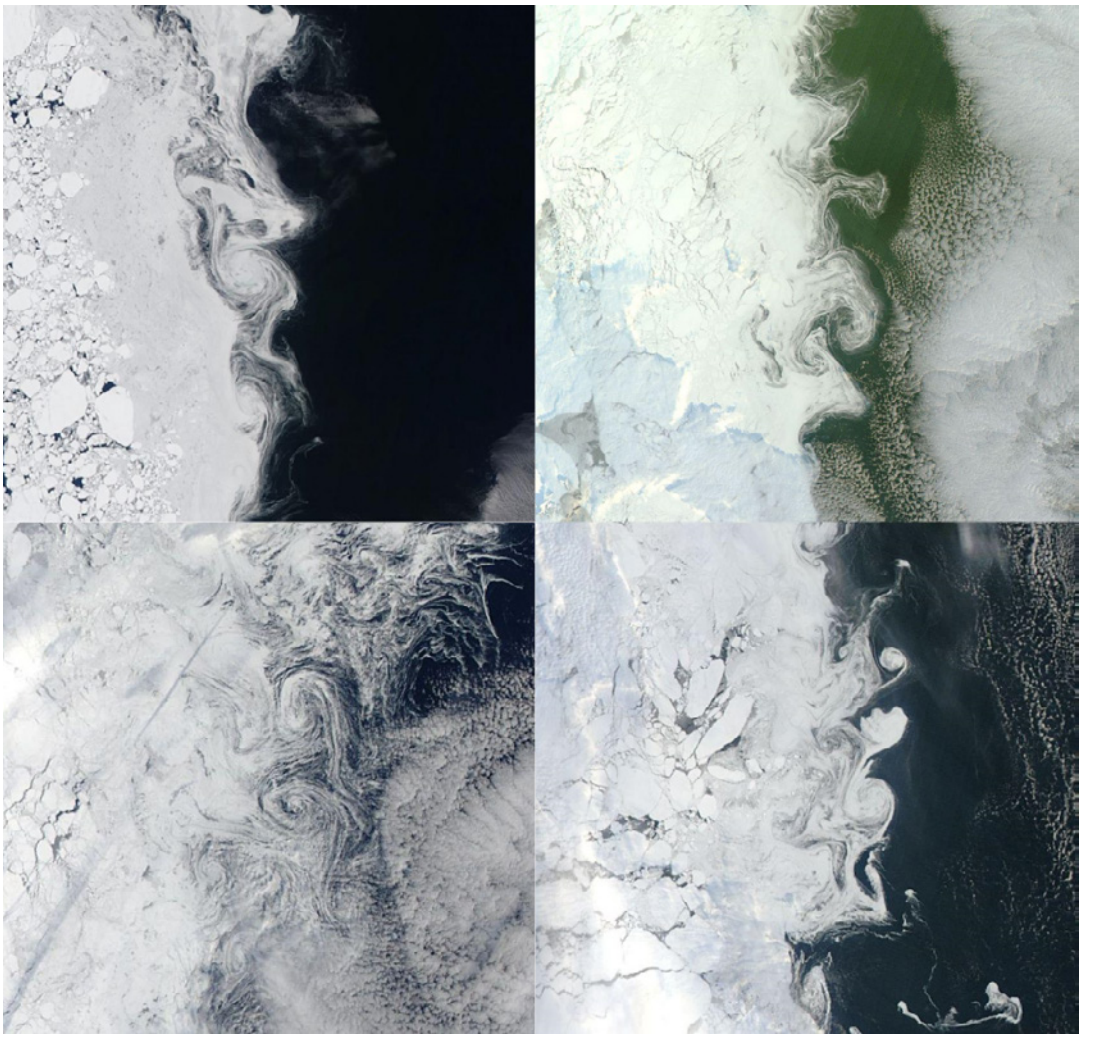
"Whirlpools" of seawater the size of Bjørnøya sometimes break away from unstable ocean currents. Swirling forward a few kilometres per day, they can last for months and carry the properties of their parent currents over vast distances. Oceanographers call these whirlpools "mesoscale ocean eddies".

GLOBALLY, MESOSCALE EDDIES redistribute substantial amounts of water and heat, making them important to ocean and climate dynamics. In addition, these spinning columns of fluid are partially isolated habitats which can concentrate plankton and create biological hotspots.

The North Atlantic Current, after moderating Norway's northern climate, continues northward and enters the Arctic as a system of boundary currents flowing along the west and north coasts of Svalbard. Clearly, the eddies it spawns could be important for redistributing heat, salt, and nutrients from the Atlantic to the Arctic Ocean.

But little was known about the prevalence, distribution, and seasonality of eddies north of Svalbard. These waters are logistically challenging, and even the best field campaigns are limited in time and space. Realistic circulation models can fill in gaps in the observational record. We therefore surveyed eddy activity in this region using a sea ice and ocean model called S800 (see fact box on page 27).

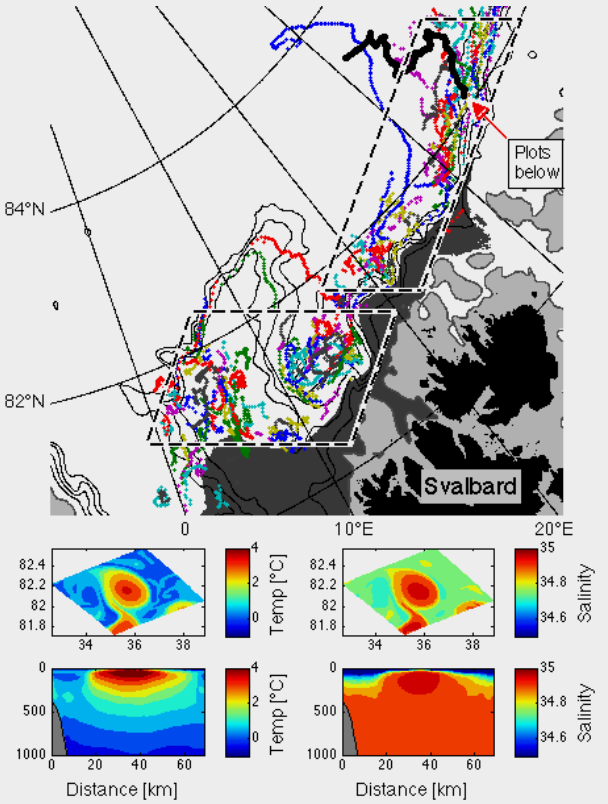
When we encounter eddies during a research cruise or with a remotely-deployed instrument like an ocean glider, we measure the physical and biogeochemical properties of the water within the eddy. This gives us a detailed picture of the eddy's properties and behaviour at one point in time, but it's just a snapshot. We won't know how the eddy evolves after we stop observing it. With a model, we can follow eddies through time and document how they evolve. To do this, we initialised the S800 model with direct observations and other data, then tracked Atlantic Water eddies using their characteristic fingerprint: warm, salty, spinning areas with a diameter of a few kilometres.



Satellite photos of eddies in the transition zone from sea ice to open ocean in eastern Fram Strait. Large, fragmented ice floes can be seen on the left side of each photo. The spiraling features of loosely packed sea ice near the centre of each photo show the locations of ocean eddies, each about 10-20 km in diameter. The hazy features to the right are clouds. The photos were taken by the MODIS Aqua satellite on (clockwise from top left) 6 June 2015, 25 February 2016, 9 March 2016, and 10 April 2016 and can be viewed at worldview.earthdata.nasa.gov.

FURTHER READING:

Crews L, Sundfjord A, Albretsen J, Hatterman T. (2018) Mesoscale eddy activity and transport in the Atlantic Water inflow area North of Svalbard. J. Geophys. Res. Oceans. doi:10.1002/2017JC013198



The top panel shows the paths taken by detected eddies. The coloured dots are the daily locations of the eddies. Dark grey: average location of the boundary current. Light grey: water shallower than 150 m. The black lines show where the ocean depth is 500 m, 1000 m, 1500 m, and 2000 m. The dashed boxes outline the regions of differing eddy behaviour described in the text. The bottom panels show temperature and salinity in horizontal (depth 150 m) and vertical cross sections through an eddy that formed in late autumn 2006. They show that the eddy is warmer and saltier than the surrounding Arctic Ocean water. The eddy's trajectory is shown by the bold black track on the upper right corner of the map. The red arrow indicates the position of the cross sections. (Adapted from Crews et al. 2018)

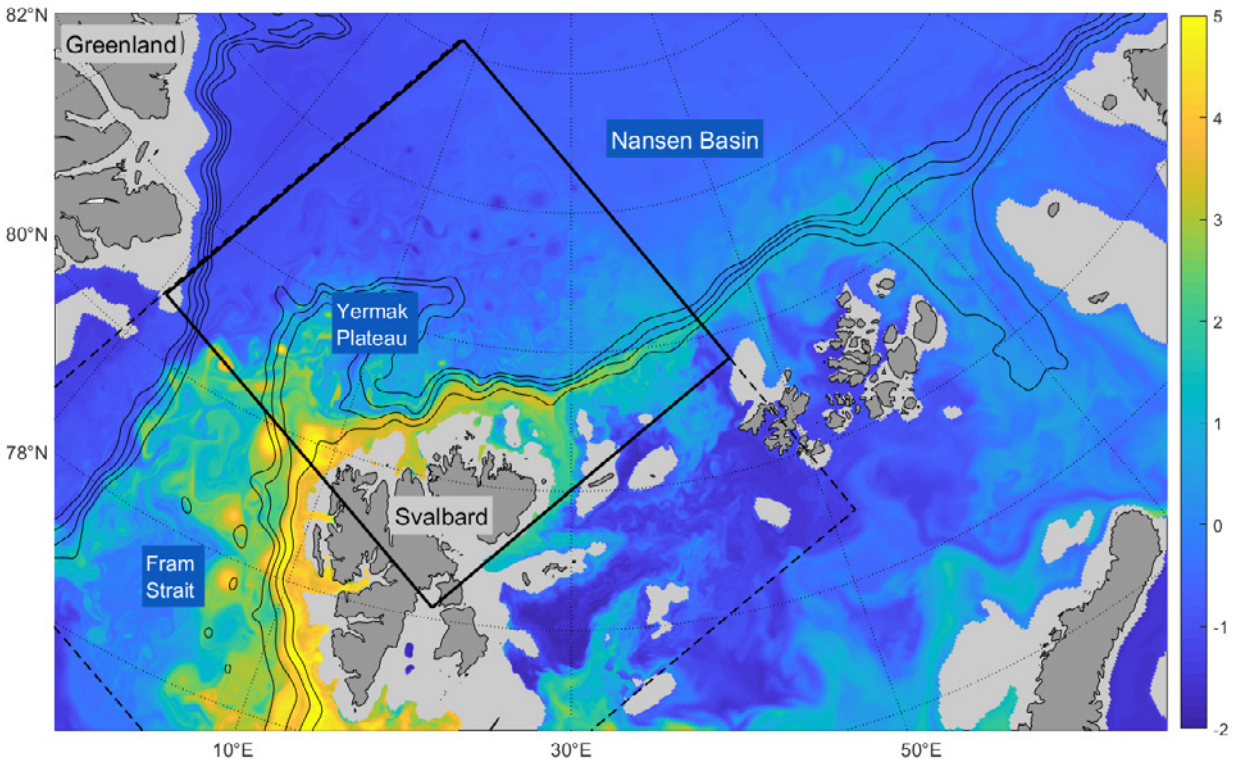
WHERE AND WHEN DO EDDIES FORM?

To figure out where and how eddies form, we examined ocean properties in and near the boundary current. In general, currents are more unstable and more likely to form eddies when there are large changes in velocity and small differences in density between vertical layers of the ocean. We found that the current was most unstable, and that velocity anomalies were also strongest in winter.

When we mapped the eddies detected in the model we found two patterns of eddy behaviour. Eddies northeast of Svalbard formed more frequently in winter, in sync with current instability, and traveled in relatively straight lines. The longest-living and farthest-traveling eddy of our study formed in this region. It lasted for eight months and traveled 250 km. Eddies north and northwest of Svalbard were more likely to form in summer and they took more roundabout paths. We believe their paths were steered by local ocean floor topography, and the timing of their formation - out of phase with current instability - may relate to a local change in current dynamics when the current flows across the shallow Yermak Plateau.

EDDIES' ROLE IN ARCTIC OCEAN HEAT BUDGET

In addition to the locations of eddies in time and space, we were also interested in eddy-mediated transport of water from the boundary current to the Arctic Ocean. We found that the eddies are located in the halocline, a layer that insulates the cold surface waters from the warmer deep waters of the Arctic Ocean. This is important because as the eddies break down, the water they contain is injected into the ocean around them. We calculated that the total heat carried by these Atlantic Water eddies would be enough to melt 1.5 m of sea ice thickness if that heat were mixed upward to the ocean surface. Luckily for the fate of the sea ice, eddies don't act like straws, relocating water directly between depths, but more like salad spinners, diffusing water outward at the same depth. In the future, we hope to study how eddies affect ocean properties at different depths. This will help us better understand how eddies interact with arctic sea ice and how they influence marine ecosystems. ■



Modelled ocean temperature in our study area at 150 m depth on an arbitrary day (1 September 2007). The warm colours show the warm Atlantic Water flowing along the west and north coasts of Svalbard. The black square is the portion of the S800 model domain used in our study; the dashed line shows the full S800 domain. (Adapted from Crews et al. 2018)

The S800 model

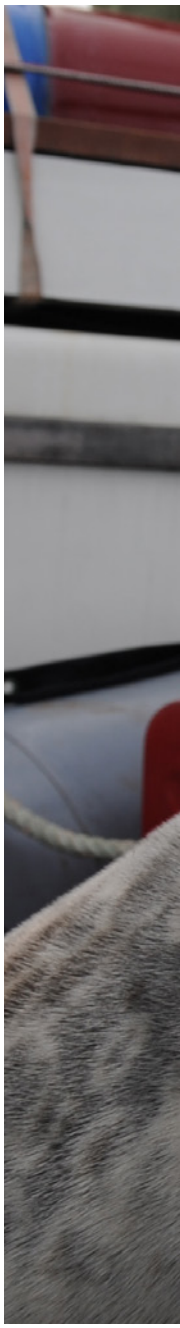
This study builds on results from two projects within the Fram Centre's Arctic Ocean Flagship. The A-TWAIN project is a multi-year measurement programme established to understand the fate and effects of Atlantic-origin water in the region north of Svalbard. The ModOIE project aims to create a coupled numerical model system for ocean–sea ice–ecosystem interactions in the Arctic. The model used in this project, S800, is one product of that effort.

S800 simulates ocean currents, temperature, salinity, and sea ice conditions for the waters surrounding Svalbard. To test the model, we compared the conditions it simulated to observations made by cruises and moorings, and found that S800 can reproduce the hydrography of the boundary current in Fram Strait and north of Svalbard. This means that the model can be used to study many different ocean processes in the region.

S800's high horizontal resolution made it particularly suitable for studying eddies. Model resolution is like pixel count in a photograph. To obtain a clear image of stones on a beach, you need a camera than can resolve the outlines of the stones. Since eddies in the Arctic are only a few kilometres wide, the S800 model, with its 800 × 800 metre "pixels", was well suited to the task.

Charmain D. Hamilton, Kit M. Kovacs, Jon Aars and Christian Lydersen // Norwegian Polar Institute
Rolf A. Ims // UiT The Arctic University of Norway

Polar bears and ringed seals "decoupling" in a changing Arctic



Ringed seals are the most important prey species for polar bears throughout the Arctic, but successful predation is strongly influenced by the presence of sea ice. What consequences will sea-ice declines have for this classical predator–prey relationship and how might that affect other arctic species?

POLAR BEARS AND RINGED SEALS are sea-ice specialists that live year-round in the Arctic. Polar bears use sea ice to travel between areas and as a platform for hunting ice-associated marine mammals. Ringed seals make breathing holes in land-fast ice, above which they dig lairs in the snow that accumulates on the surface of the ice. Lairs are used for birthing and nursing of pups in the spring and for resting during winter; they provide protection against predators and cold conditions. Ringed seals also forage on ice-associated prey and use sea ice for moulting (replacement of the hair and upper layers of skin) in summer and for resting throughout the year. Polar bears and ringed seals are tightly linked, as ringed seals are the primary prey of polar bears.

HISTORICAL PREDATOR–PREY RELATIONSHIP

In Svalbard, polar bears and ringed seals have two movement strategies - after the breeding season (and for ringed seals, after moulting), they either travel offshore to the marginal ice zone of the Barents Sea/ Arctic Ocean, or remain coastal, often associated with glacier fronts that terminate in the sea. Areas close to these "tidal" glacier fronts are the best pupping areas for ringed seals in spring and important foraging areas for Svalbard's seals throughout the year. Almost year-round coverage of sea ice in glacier front areas was the norm until the past decade in eastern Svalbard, which is also the core area for polar bears. When sea ice was present, polar bears could hunt ringed seals readily by still-hunting at their breathing holes or stalking them on the ice.

Ringed seal equipped with a biotelemetry tag.
Photo: Kit Kovacs and Christian Lydersen / Norwegian Polar Institute

CONSEQUENCES OF SEA-ICE DECLINE

Sea ice conditions in Svalbard changed abruptly in 2006; the altered sea-ice regime persists to the present day. The formation of land-fast ice decreased across the archipelago, with the largest declines happening along the west coast. When/if the fjords freeze now, they tend to do so late in winter (not allowing time for snow accumulation in many areas), and the sea ice does not persist into the summer.

We used data from biotelemetry devices deployed on ringed seals and polar bears (2002-2004 and 2010-2013) to investigate the effects of the sea-ice declines on these two species in coastal areas in eastern Svalbard. In spring, polar bears and ringed seals behaved the same before and after the sea-ice decline. Environmental changes in these areas are apparently not yet severe enough to impact these species - at least not in spring. However, during the summer and autumn, polar bears spent much less time close to tidal glacier fronts following the sea-ice collapse (decreased from 67% to 32% of their time), while ringed seals continued with business as usual. They still associated tightly with tidal glacier fronts and continued to spend a normal amount of time resting on ice (i.e. the time they are most vulnerable to polar bears). This led to a large decline in spatial overlap between polar bears and ringed seals in coastal areas, decoupling this classical predator-prey system for extensive periods of the year.

The decrease in spatial overlap between ringed seals and polar bears is almost certainly due to decreased hunting opportunities for polar bears. As the land-fast ice now melts much earlier in the spring, ringed seals must increasingly use calved pieces of glacier ice for resting. Bears can successfully hunt seals hauled out on glacier ice by sneaking up on them in the water, diving during the last part of the "stalk" and subsequently popping up in front of the seal and killing it. However, this is a specialized hunting strategy that few bears master.

Successful outcome for a polar bear hunting a seal hauled out on a calved piece of glacier ice. *Photo: Kit Kovacs and Christian Lydersen / Norwegian Polar Institute*

Polar bear equipped with a biotelemetry tag. *Photo: Jon Aars / Norwegian Polar Institute*

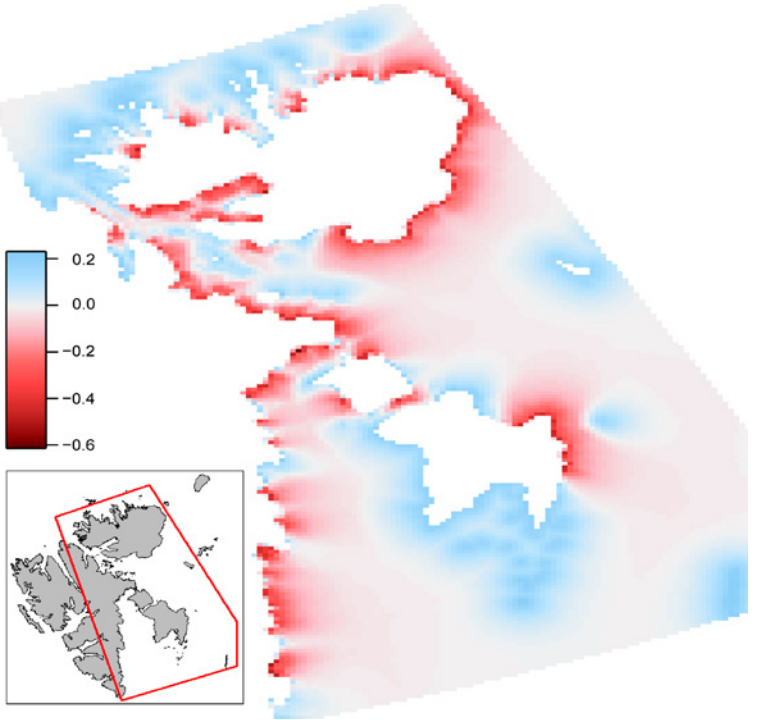
After the sea-ice decline, polar bears moved greater distances per day in the summer, likely looking for alternative food sources. They now spend significantly more time close to colonies of ground-nesting birds such as ducks and geese (increased from 2% to 8% of their time during the summer). Their presence is having quite drastic consequences for these colonies, as the bears now consume over 90% of the eggs in some areas.

FUTURE OF THE COASTAL STRATEGY

The future of the coastal movement strategy of ringed seals and polar bears is uncertain. Tidal glacier fronts in Svalbard are retreating onto land, which is decreasing the number of these important foraging and breeding areas. Polar bears will likely continue to diversify their diets, consuming reindeer, whale carcasses, seabirds and vegetable matter. However, it is questionable if terrestrial food can nutritionally compensate for eating fewer fat-rich seals and it is also uncertain whether these other animal populations can sustain polar bear predation pressure. ■

FURTHER READING:

Hamilton CD, Kovacs KM, Ims RA, Aars J, Lydersen C (2017) An Arctic predator–prey system in flux: Climate change impacts on coastal space use by polar bears and ringed seals. J Anim Ecol 86:1054-1064 (doi:10.1111/1365-2656.12685)



Relative change in spatial overlap between polar bears and ringed seals in Svalbard after the sea-ice decline occurred.

Tore Haug, Bjarte Bogstad, Randi Ingvaldsen and Lars-Johan Naustvoll // Institute of Marine Research

A warmer Arctic means trouble for local species

As the Arctic warms, more species are moving northward. This is a bonus for the animals from the south, but it will make life harder for several of the species endemic to the Arctic.

TOUGHER COMPETITION FOR FOOD

Marine mammals in the Arctic include both species that live there all year round and species that migrate there to feed during the productive summer months. For the permanent residents, drift ice is essential. Several species of seal use the ice floes to give birth to their pups, shed their fur and recuperate. The drift ice also gives effective protection against enemies such as killer whales.

Every year, several species of whales migrate north to the Arctic to partake of its bountiful summer food supply. Receding ice means that several prey species such as crustaceans and fish move north, and the predators follow them farther and farther towards the Arctic Ocean.

This is probably not much of a problem for the whales, but the local species face increased competition for what food is available.

CLIMATE CHANGE AFFECTS THE HARP SEAL

Fish moving north compete with seals and whales for food if they have similar diets. Cod is one such example. It appears that the growing population and expanding distribution of cod contribute to reduced blubber thickness in harp seals and minke whales. Blubber thickness says something about the state of health of these animals. Marine mammals build up most of their blubber during the intensive grazing season each summer. The rest of the year – when food is scarce and the animals are busy doing other things like giving birth and mating – they fast for longer and shorter periods, using stored fat for energy. Marine mammals also rely on blubber to protect themselves against the cold.

We see that harp seals are giving birth to fewer pups than before. With worsening conditions on drift ice, where the seals give birth, fewer pups survive. When also faced with harsher competition in their feeding areas along the ice edge in the north, the harp seal population is likely to decrease over time.

ARCTIC SPECIES MAY DIE OUT

The changes occurring in the Arctic are dramatic, and they are happening fast. Significant warming, reduced ice cover and ocean acidification have been observed in recent years. In future years, the ocean may grow even warmer, further reducing the amount of sea ice. Several factors will affect food production.

We cannot predict the consequences for every species. Some will cope with the changes and may increase in number, while others will encounter major problems and may risk extinction.

WE NEED TO UNDERSTAND THE BIG PICTURE

Everything within an ecosystem is interdependent. We need to examine how the productivity of phytoplankton and zooplankton is changing, how the distribution and migration patterns of fish stocks evolve, and how the living conditions of top predators like seals and whales are affected.

We must understand and be able to calculate how climate change affects individual species, and how different species influence each other. Researchers are pursuing this knowledge even now. At the Institute of Marine Research, we are examining the mechanisms underlying, and the long-term implications of, climate change in the Arctic Ocean.

But there is still much we do not know. What we do know for certain is that research is crucial to our ability to forecast the fate of these species in a warmer Arctic. ■

Peter Thor and Allison Bailey // Norwegian Polar Institute

Will ocean acidification affect arctic zooplankton populations?

Calanus glacialis. Photo: Allison Bailey / Norwegian Polar Institute

Most readers of Fram Forum know that the carbon dioxide we humans release is changing the climate. Fewer are aware that it is also changing the chemistry of seawater. About a third of the CO_2 we emit is taken up by the oceans, where it lowers the water's pH. That has consequences for marine ecosystems.

In the ocean, zooplankton are a crucial link between energy-producing phytoplankton and fish. We have studied how changing acidity might affect zooplankton. Although recent research has revealed a complex web of interactions between plankton species, the notion of a linear food chain from phytoplankton via zooplankton to fish is still valid as a model for the transport of energy from primary producers to fish stocks in arctic waters. There, most fish larvae rely on zooplankton for food. This makes the arctic ecosystem particularly vulnerable to perturbations that affect zooplankton productivity. One focus of concern is how arctic zooplankton populations will evolve in the face of climate change and ocean acidification (OA).

Just as arctic ecosystems are vulnerable to perturbation, the waters of the Arctic are vulnerable to OA. Present OA rates are far higher here, and they are expected to remain so for three reasons. First, melting sea ice has low capacity to buffer acidity. Second, although the Arctic Ocean constitutes only 1% of the global ocean volume, it receives 11% of the discharge from rivers, which not only has low buffering capacity but also brings significant amounts of terrestrial carbon, which may ultimately be transformed to CO_2 by microbial respiration. Finally, increasing inflow from the North Atlantic transports large amounts of anthropogenic CO_2 to the Arctic Ocean. Arctic organisms are therefore the first to face the effects of OA and will face stronger OA in the future.

Unfortunately, arctic species may also be less well equipped to handle decreasing pH than most other marine invertebrates. Unlike lower-latitude species that tolerate a wide range of temperatures, true polar species perform best at low temperatures. But this advantage comes at a price. Polar marine invertebrates have less energy available for cellular pH regulation.

Arctic zooplankton biomass is dominated by three copepod species: *Calanus hyperboreus*, *C. glacialis*, and *C. finmarchicus*. Much research has focused on these copepods, particularly *C. glacialis*, which is abundant in the shallow shelf seas surrounding the Arctic Ocean, and is the primary prey for fish larvae, birds, and baleen whales. In this as in many other species, OA effects seem to vary with developmental stage.

Somewhat unexpectedly, development of the early nauplius larval stages seems largely unaffected by OA. However, development rates appear to be maintained only through upregulation of cellular acid/base regulation, at the expense of vital physiological functions such as DNA repair.

In contrast, the later copepodite larval stages seem more sensitive. Studies show that OA will increase the cost of biosynthesis, which may result in poorer growth. One study showed that the growth potential may decrease by as much as 50% along the Svalbard west coast at OA levels predicted for the year 2100. Such changes will have serious implications for the *C. glacialis* population in these waters. They will prolong larval development time and reduce the body size of copepodites (preadult stages) and adult individuals.

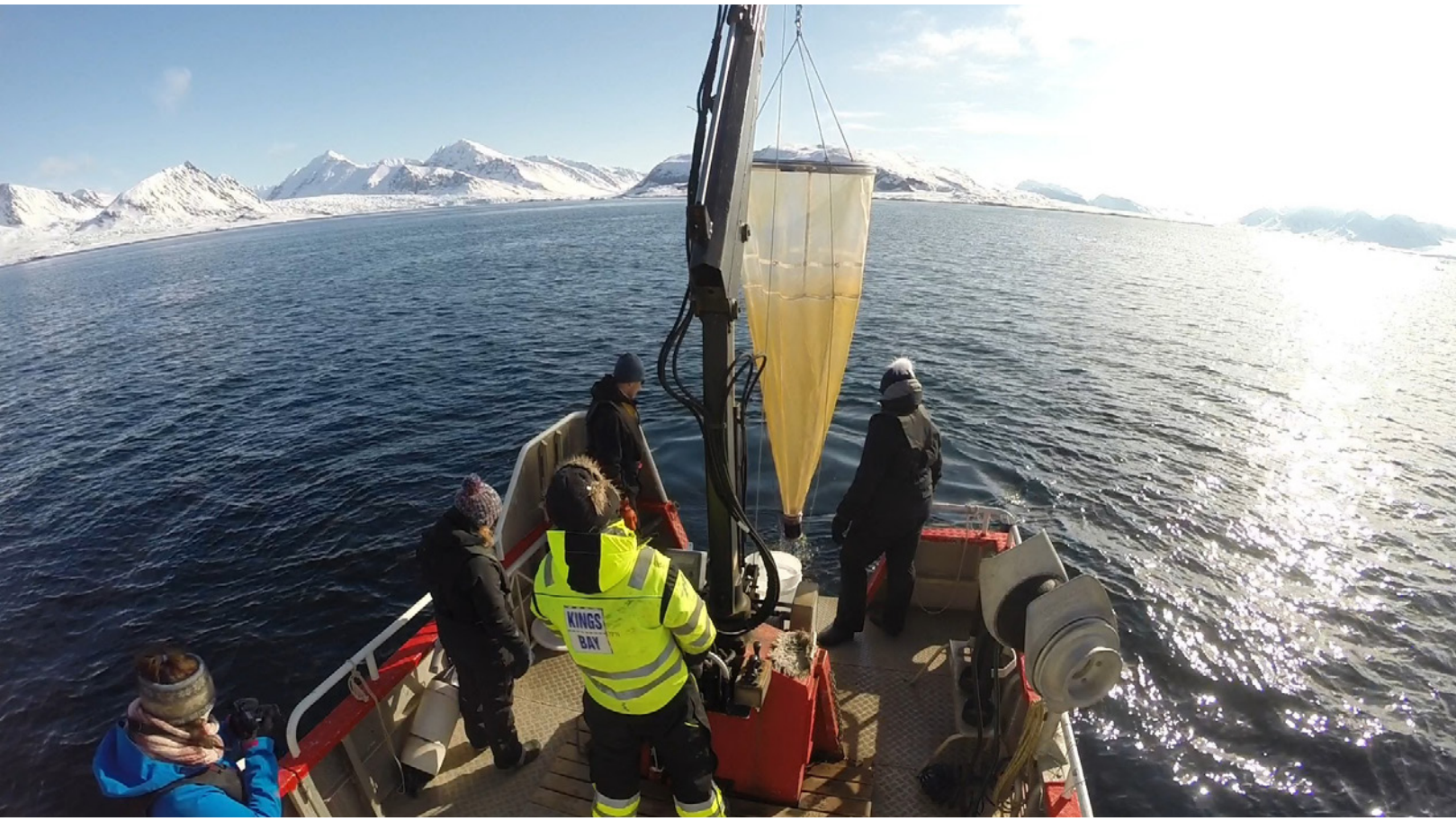
The last copepodite stage seems unresponsive to increased pCO_2, likely because these copepodites are metabolically different than the earlier stages. While somatic growth is the main goal of the earlier stages, the metabolism of the last preadult stage is reconfigured to accommodate winter dormancy (diapause), when extracellular pH can be as low as 5.5. Finally, the fecundity of adult *C. glacialis* seems unaffected by high pCO_2 in terms of egg production, egg hatching success and timing.

Pteropods are another group of keystone species in the Arctic. While their biomass does not rival that of the *Calanus* species, they also contribute to the diet of many fish species. These mollusks build calcium carbonate shells, which are sensitive to corrosion when pH decreases. Studies have shown that shell integrity is compromised at OA levels predicted for year 2100 with increased mortality as a result.

But there are forces that may counteract the negative effects of OA. Studies show that OA effects vary among populations. Unlike their conspecifics along the Svalbard coast, *C. glacialis* from Disko Bay on the West Greenland coast seem entirely unaffected. This indicates the possibility of rescue from severe effects of OA. Evolutionary rescue from environmental changes can come about through advantageous mutations in affected populations, by immigration from

OCEAN ACIDIFICATION

The ocean is in gas equilibrium with the atmosphere, so when atmospheric CO_2 increases, more CO_2 is taken up by oceans. There, it reacts with water to form carbonic acid. The most prominent effects of this reaction are a decrease in the seawater's carbonate ion concentration, and a lowering of its pH (a phenomenon termed ocean acidification). The world's oceans are estimated to have absorbed 155 billion tonnes of anthropogenic carbon between 1750 and 2010, roughly one third of the CO_2 emitted by human activity over that period. This has lowered the global mean pH of the surface ocean from 8.13 in pre-industrial times to the present-day 8.05. The pH scale is logarithmic, so this corresponds to a 20% increase in acidity. Ocean models predict that this trend will continue; we expect a further decrease of 0.4 pH units by 2100.



Catching copepods in Kongsfjorden. *Photo: Peter Thor / Norwegian Polar Institute*

more fit populations, or by fast adaptation. In invertebrates, mutations occur too seldom to save Svalbard's copepods, but if copepods in other parts of the Arctic are as tolerant as the Disko Bay population, migration may act to counter OA effects. Also, our own previous studies have shown that copepods can adapt rapidly to OA (see Fram Forum 2014).

There is no doubt that the Arctic will change, and along with the increase in temperature, one of the main changes is the decrease in pH. Although our knowledge on the effects of Arctic OA is increasing, we still know little about how these changes will affect the entire pelagic community, including fish stocks. During our work in the Fram Centre Ocean Acidification Flagship, we have focused particularly on effects on the keystone zooplankton species, the *Calanus* copepods. Ultimately, we hope our work will enable ecosystem models to project how future OA might affect the entire arctic ecosystem. ■

FURTHER READING:

Thor P, Bailey A, Dupont S, Calosi P, Søreide JE, De Wit P, Gushelli E, Loubet-Sartrou L, Deichmann I, Candee M, Svensen C, King AL, Bellerby R (2017) Contrasting physiological response to future ocean acidification among Arctic copepod population. Global Change Biology DOI: 10.1111/gcb.13870

Thor P, Browman H, Halsband C (2014) Ocean acidification – CO_2 effects in Northern waters. Fram Forum 2014: 40-43


IMO 7638351
LGKI
SWL 1.1T

Paul A. Dodd, Torgeir Blæsterdalen and Laura de Steur // Norwegian Polar Institute
Michael Karcher // Ocean-Atmosphere Systems
Tore Hattermann // Akvaplan-niva

Pacific water in the Arctic Ocean and Fram Strait

The amount of Pacific water in the upper layers of the Arctic Ocean varies over time, affecting the amount of freshwater discharged to the Nordic Seas through Fram Strait. Observations show higher fractions of Pacific water passed though Fram Strait during the 1990s than today, possibly due to changes in the large-scale atmospheric circulation.

The Norwegian Polar Institute's research vessel *Lance* encountered rough weather during a research cruise in Fram Strait in September 2017. Nutrient samples have been collected during 21 cruises along this section between 1990 and 2017, providing a unique dataset with which to investigate long-term changes in the outflow from the Arctic Ocean. *Photo: Paul A. Dodd / Norwegian Polar Institute*

WHY MONITOR PACIFIC WATER?

The Pacific inflow though the Bering Strait is a significant source of heat and freshwater to the Arctic Ocean. The paths Pacific water takes though the Arctic Ocean are thought to be affected by the large-scale atmospheric circulation, which means that its contribution to the Arctic Ocean outflow will vary. Pacific water contains more silicate than other halocline water masses, and can therefore affect silicate-limited diatom blooms, which enhance carbon sequestration in the northern North Atlantic. For example, a diatom species that had been absent from the North Atlantic for 800 000 years was reintroduced in 1997-1998 when strong pulses of Pacific water coincided with a reduced sea ice extent. Variations in the volume of freshwater exported from the Arctic Ocean can also modulate the large-scale overturning circulation by affecting deep water convection.

HOW DO YOU RECOGNISE PACIFIC WATER?

It is difficult to identify Pacific water in the European Arctic from its temperature and salinity alone. Fortunately, we can detect it by measuring nutrients in the water. The Redfield ratio quantifies the relationship between nitrogen and phosphorus atoms, which is remarkably stable throughout the world's oceans. However, due to strong denitrification over the Chukchi Shelf, Pacific water entering the Arctic Ocean is depleted in nitrate, and can be identified by deviations from the Redfield ratio. The Fram Centre TRIMODAL project - which uses tracers, atmospheric indices and models to study changes in Arctic Ocean inflow/outflow through Fram Strait - collated 21 new and existing sections of nutrient measurements and used them to investigate the fractions of Pacific water present in Arctic Ocean outflow between 1990 and 2017.

DOES PACIFIC WATER REACH FRAM STRAIT?

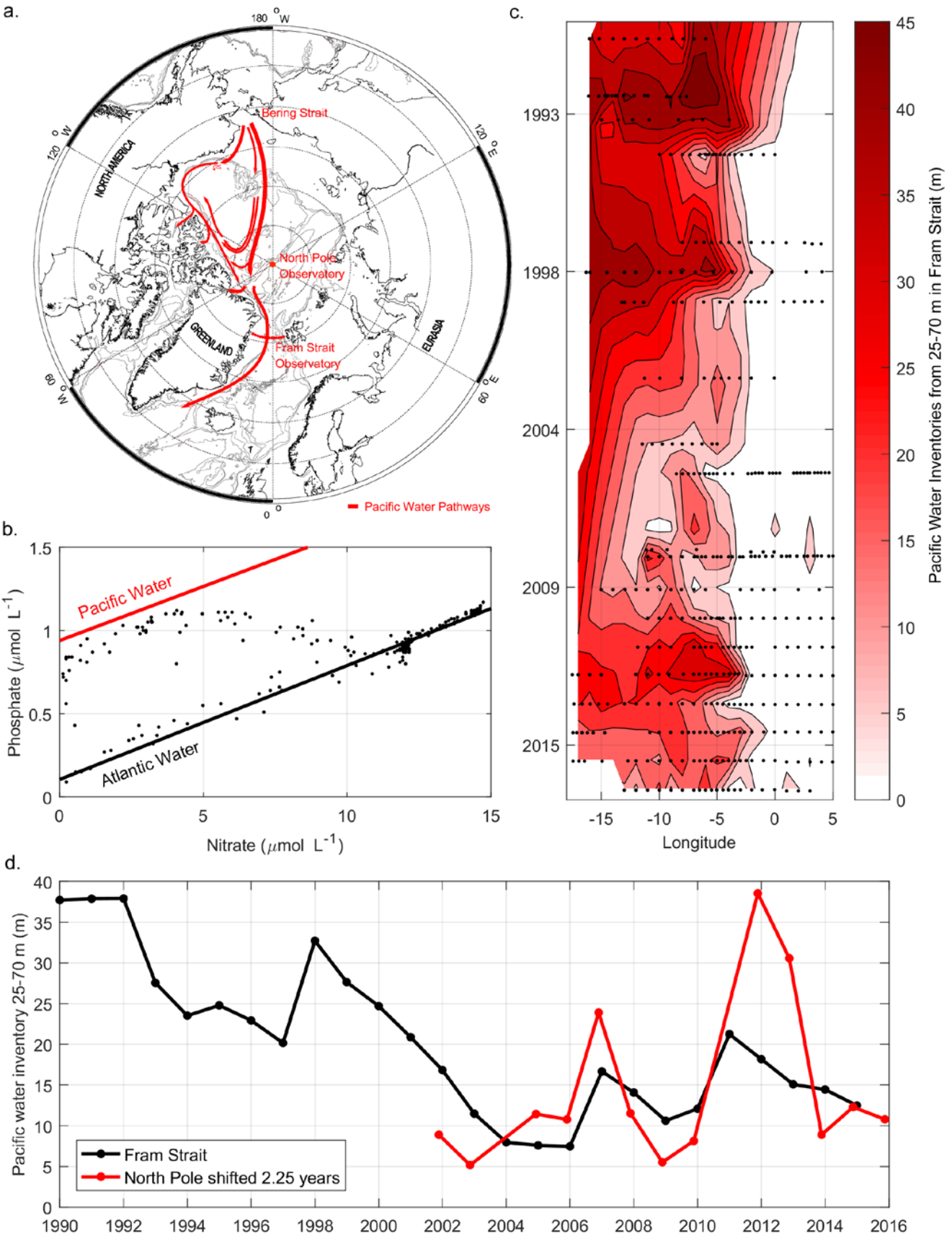
Very high Pacific water inventories were observed in the late 1990s, accounting for up to 90% of the upper halocline water found between 25 and 75 m in the core of the East Greenland Current. However, the contribution of Pacific water to the outflow is highly variable and in 2006 there was almost no Pacific water in Fram Strait. Significant pulses of Pacific water were observed in 1992, 1998, 2007 and 2012. The frequency of pulses has not changed with time, but pulses released in the 1990s contained much higher fractions of Pacific water than those released in 2007 and 2012. Pacific water inventories are typically highest in the core of the East Greenland Current and lower over the East Greenland Shelf. Pacific water maxima are slightly sub-surface, due to dilution by melting sea ice in the top 25 m.

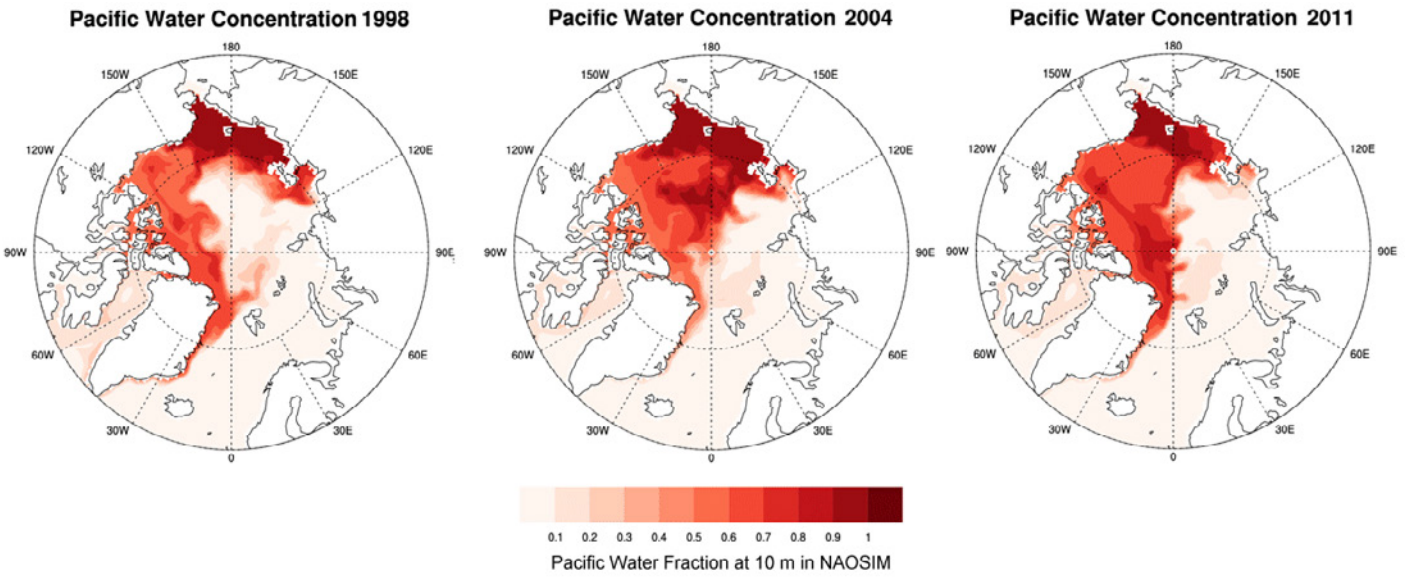
a) Map showing Pacific water pathways through the Arctic Ocean.

b) Samples from the 1998 Fram Strait section show the different nitrate and phosphate relationships in Pacific and Atlantic water.

c) Hovmöller diagram of Pacific water inventories in Fram Strait. Imagine looking down at Fram Strait with Greenland on the left and Svalbard on the right. Colours indicate the total amount of Pacific water over time, from the early 1990s at the top to the mid-2010s at the bottom.

d) Pacific water inventories at Fram Strait and at the North Pole.


a.
180 °W
120 °W
120 °E
60 °W
60 °E
0 °
NORTHAMERICA
EURASIA
GREENLAND
Bering Strait
North Pole Observatory
Fram Strait Observatory
Pacific Water Pathways
b.
Pacific Water
Atlantic Water
Phosphate (μmol L-1)
Nitrate (μmol L-1)
c.
1993
1998
2004
2009
2015
Longitude
Pacific Water Inventories from 25-70 m in Fram Strait (m)
d.
Pacific water inventory 25-70 m (m)
Fram Strait
North Pole shifted 2.25 years



Maps showing the fraction of Pacific water at 10 m depth predicted by NAOSIM in years when high (1998, 2011) and low (2004) inventories were observed in Fram Strait.

PACIFIC WATER AT THE NORTH POLE

Nutrient samples were collected at the North Pole Environmental Observatory from 2005 to 2015, providing 10 years of overlap with the Fram Strait Observatory 1200 km downstream (see map on page 39). After adjustment for a calculated advection time of about 2.25 years, peaks in Pacific water inventories at the two locations are well aligned. The co-variability at Fram Strait and the North Pole suggests that Pacific water inventories in the Arctic Ocean outflow are modulated by large-scale changes in the Beaufort Gyre and the Transpolar Drift - two major currents in the Arctic Ocean - rather than by local process in Fram Strait.

CONNECTION TO THE ATMOSPHERE

The Arctic Oscillation (AO) is a non-seasonal variation in atmospheric pressure north of 20°N. A positive AO index describes abnormally low pressure in the Arctic, paired with abnormally high pressure at about 37-45°N. A negative AO index describes the inverse pressure situation. It has been suggested that transport of Pacific water towards Fram Strait is more efficient when the AO index is positive, whereas a persistently negative AO should reduce the Pacific water contribution to the outflow through the Strait. In the early 1990s the AO exhibited a significant positive phase, but shifted in the late 1990s to a more neutral state that continues to this day. The shift in AO state in the late 1990s corresponds well with the decline of Pacific water inventories observed in Fram Strait and the system seems to have responded to the change in forcing within 3-4 years.

NUMERICAL MODEL EXPERIMENTS

Although there is a long time series of nutrient measurements in Fram Strait, these observations only allow us to compare the situation in Fram Strait with the prevailing atmospheric conditions over the Arctic in years when nutrient measurements are available. Researchers in the Fram Centre TRIMODAL project have added a Pacific water tracer to two different numerical model simulations. These model tracer experiments can be validated by comparison with the long time series of nutrient measurements in Fram Strait and are currently being used to investigate the pathways Pacific water takes though the Arctic Ocean at other times and under different atmospheric conditions. ■

Elina Nystedt and Torgeir Blæsterdalen collecting nutrient samples during the 2017 Fram Strait Cruise. Round-the-clock operations allow an extensive biogeochemical sampling program.
Photo: Paul A. Dodd / Norwegian Polar Institute

Kjersti Opstad Strand // Institute of Marine Research

Might Northeast Arctic cod extend its habitat to northeast Greenland?

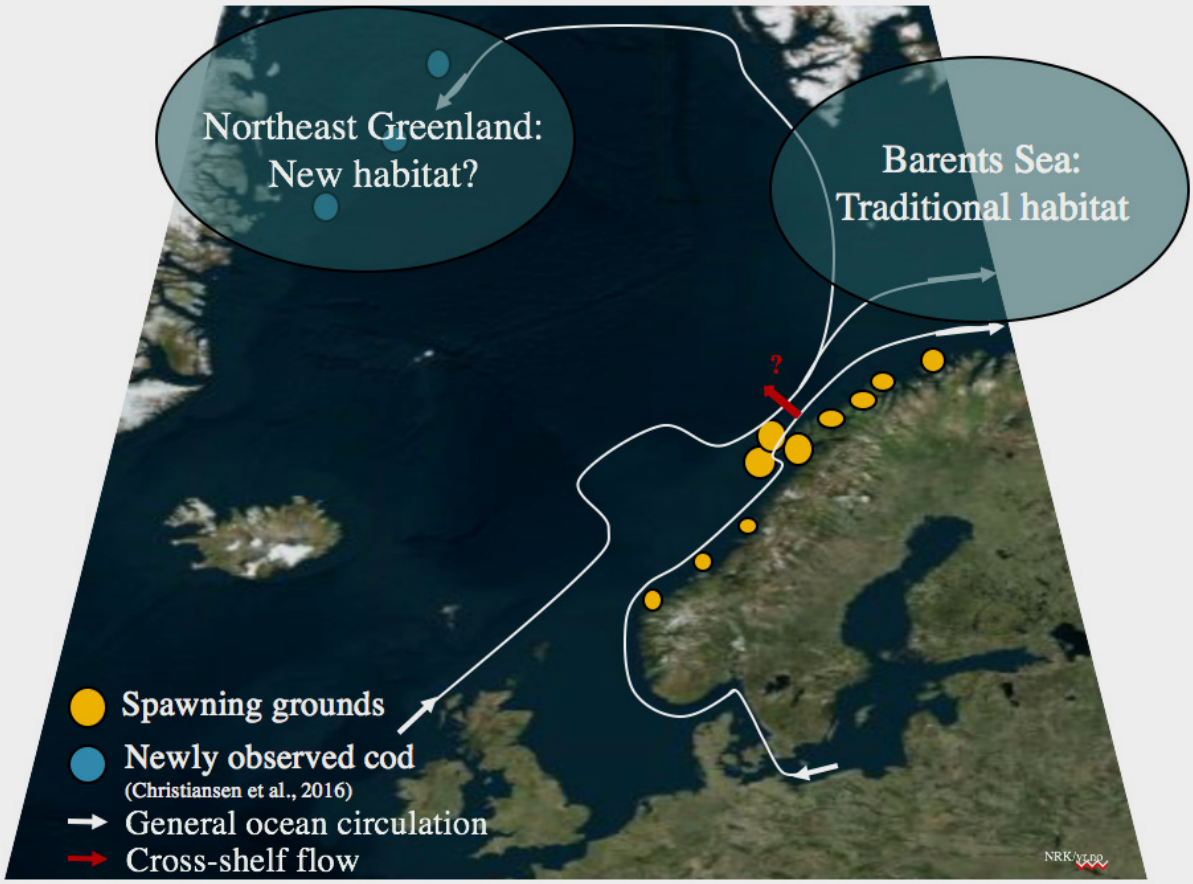
Young Northeast Arctic cod that drift into the deep water of the Norwegian Sea are doomed. At least that's what everyone believed. Dynamic modelling shows that some fish may eventually make it to their nursery in the Barents Sea. But given the right winds, some might reach the Greenland Shelf. Then what?

The Northeast Arctic cod starts its life as an egg drifting with the ocean currents along the coast of Norway from Ålesund and the main spawning grounds around Lofoten to Finnmark. The drifting eggs hatch after about 20 days and continue to drift towards the nursery area in the Barents Sea. This journey starts at the same time every spring, with peak spawning 1 April.

IN DEEP WATER

Norway lies at the polar front, the transition zone between cold arctic air and warmer tropical air masses. This means that the weather varies continuously: low-pressure systems pass through, disrupting the prevailing direction of the upper ocean currents. A young Northeast Arctic cod floating towards the Barents Sea can from time to time be transported out into the deep Norwegian Sea by these fickle ocean currents. In a study focused on the years from 1978 to 2015 we found that northeasterly wind conditions lasting several days to a week could transport up to a third of the newly spawned eggs, larvae and pelagic juveniles across the continental shelf into the Norwegian Sea. The Norwegian Sea is too deep for the bottom-dwelling cod to settle. The prevailing assumption for the last hundred years has been that any juvenile cod that ended up here would die. But what if they can continue to drift with the currents?

We have investigated their potential drift from 1978 to 1991, a period for which observations of pelagic juveniles in the Norwegian Sea are available. Most of the pelagic juveniles swept to the Norwegian Sea



will continue to circulate there, never finding shallow shelves to bottom settle. But as many as two of five cod "lost" into the Norwegian Sea find their way back onto the Norwegian Shelf, reaching the Barents Sea by November. A third potential drift route follows the Norwegian Atlantic current towards Svalbard and across Fram Strait towards the northeast Greenland Shelf. Of course, such a long drift journey means a much smaller chance of hitting the target. On average, less than 3% of the "lost" juvenile cod reach Greenland. However, there are large year-to-year variations, and one year, more than 12% of the pelagic juveniles ended up there.

In some years, young Northeast Arctic cod drift with the Atlantic current towards northeastern Greenland. By using ocean current models similar to those used in weather forecasting, we can calculate how many cod larvae and young pelagic juveniles drift from Lofoten to Greenland each year. Scientists from UiT The Arctic University of Norway have found adult cod on the shelf northeast of Greenland, but it remains to be established where those fish came from.
Map: Kjersti Opstad Strand / Institute of Marine Research

Young Northeast Arctic cod sometimes drift into the deep parts of the Norwegian Sea. As bottom-dwellers, these fish can only settle in relatively shallow water and most of the displaced fish will die in the Norwegian Sea. But new dynamic modelling studies suggest that some might reach the shallow northeastern Greenland Shelf.
Photo: Institute of Marine Research

WILL THERE BE ENOUGH FOOD?

According to other studies there should be enough zooplankton along the drift route, but a quantification is yet to be done. However, the northeastern Greenland Shelf is colder than the Barents Sea and the biological productivity is thus lower - at least to date. In view of the recent warming of the North Atlantic, the productivity of the Greenland Shelf might increase in the future.

Clearly, understanding the variability in the drift routes of juvenile pelagic cod gives us important clues about what areas might someday become cod habitats. Maybe our dynamic models are letting us peek into the future. ■

Scientists around the world are starting to see the value of forecasting parts of the marine ecosystems. Improved oceanic forecasting models combined with new knowledge on marine processes reveal complex connections between marine biological life and geophysical ocean conditions. The Northeast Arctic cod is just one of many species for which parts of the life cycle can be forecast, both short-term (within a single season) and over longer time scales, to investigate effects of shifting climatic conditions.

FURTHER READING:

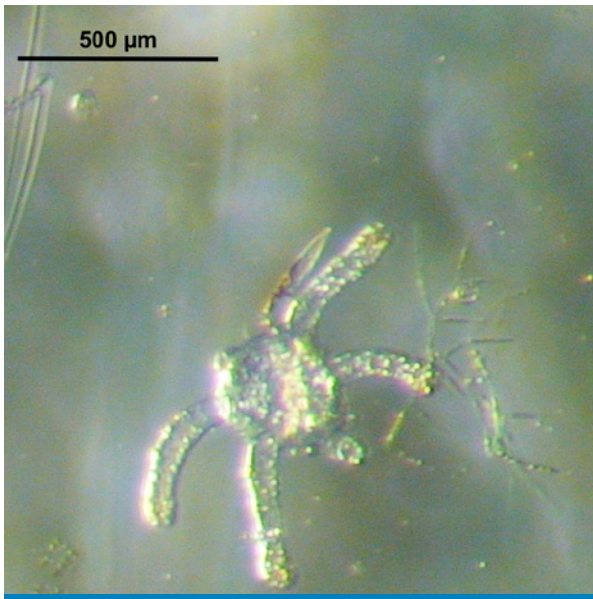
Strand KO et al (2017) The Northeast Greenland Shelf as a Potential Habitat for the Northeast Arctic Cod. Frontiers in Marine Science. DOI: 10.3389/fmars.2017.00304

Janne E. Søreide, Miriam Marquardt and Vanessa Pitusi* // University Centre in Svalbard
Sanna Majaneva // UiT The Arctic University of Norway

First record of the hydrozoan *Sympagohydra tuuli* in Svalbard sea ice

We don't know much about the tiny algae and animals living inside sea ice. Microscopic sea ice animals are rarely identified to species level because many of these tiny critters are larvae of pelagic and benthic species and look completely different from the adults. We simply don't recognise them.

SYMPAGIC MEIOFAUNA: that is the name we give to animals in the size range 20-500 μm that live in sea ice. There are many of them, and some of them are larvae. Today, DNA barcoding makes it possible to reliably identify the species of these larvae - provided the species is represented in one of the reference databases where all publicly available DNA sequences are gathered (e.g. GenBank). However, relatively few marine invertebrates have been sequenced so far, so a huge, important task remains to be done to map arctic marine biodiversity. Mapping sea ice-associated flora and fauna is particularly urgent, since summer sea ice may disappear in the near future.



The one specimen of *Sympagohydra tuuli* found in Svalbard April 2015 (from Marquardt et al. 2017). This delicate and naked hydroid is almost spherical when contracted and tubular when relaxed to its maximum length. It has four oral tentacles which can be extended to three times their length. The tips of these tentacles can be slightly orange. *Photo: M Marquardt*

*Also affiliated with UiT The Arctic University of Norway

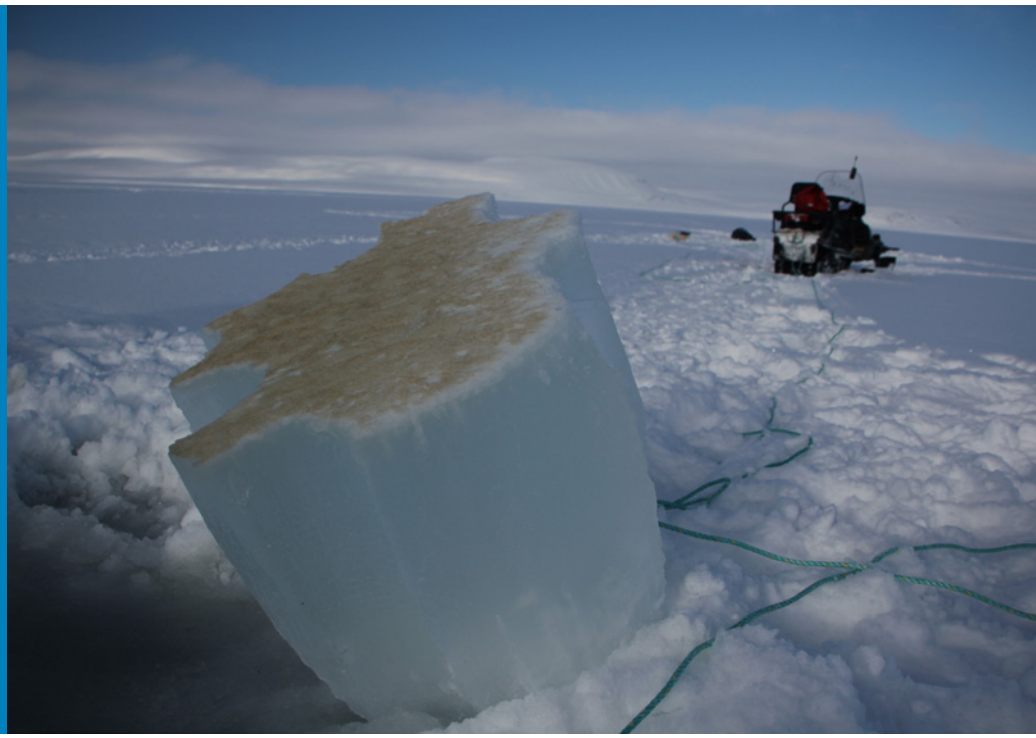
WHY IS SEA ICE A GOOD PLACE TO LIVE?

In spring, microscopic algae grow inside sea ice. These highly specialised ice algae can grow almost without light and can bloom up to two months earlier than phytoplankton in the water column below. That makes ice algae a critical early food source for many arctic marine invertebrates, giving them a head start on reproduction and growth. That's important at high latitudes where the productive season is short. In addition to being a well-filled "food-plate", sea ice also offers protection from predators. Sea ice is not solid, like freshwater ice. It contains a network of tiny brine channels due to exclusion of ions while freezing. Since space is severely restricted (diameter from micro- to millimetres) many predators do not have access to this habitat. This combination of high food concentrations and low predator pressure makes it worthwhile spending "extra calories" to compensate for the extreme temperatures and salinities in sea ice brine channels.

SYMPAGIC MEIOFAUNA IN SVALBARD

In Svalbard, reduction in coastal sea ice is particularly severe and today most West Spitsbergen fjords are largely ice-free year-round. What this means for hundreds of thousands of unknown, tiny critters living inside sea ice is an unresolved mystery. Since 2014, the University Centre in Svalbard (UNIS) has regularly studied the sea ice meiofauna community in Van Mijenfjorden, western Spitsbergen, through UNIS student courses and projects with support from the Fram Centre and Svalbard Science Forum (Arctic Field Grants).

Every year UNIS takes students to Van Mijenfjorden to sample physical and biological parameters of sea ice and the water below as part of the bachelor course AB-202 Marine Arctic Biology. Here we see students making a hole in sea ice in 2015, when the small hydroid *S. tuuli* was found for the first time in sea ice in Svalbard. *Photo: J Søreide*



The ice–water interface (underside of the sea ice) has the highest densities of ice algae (brown colouration) and sympagic meiofauna. The hydroid *S. tuuli* recorded in Svalbard was found in the lowest 3 cm. The temperatures and salinities are less extreme here since this bottom section is in close contact with the water below, which also ensures resupply of nutrients for optimal ice algae growth. *Photo: J Søreide*

Sea ice can be viewed as an upside-down benthic environment where the brine channel system corresponds to the interstitial habitats in a sandy seabed. Especially in coastal, shallow regions, there is a close biological coupling between sea ice and the sea floor. Preliminary studies in Svalbard suggest that sea ice may be an important nursery habitat for larvae of benthic animals. Up to 2 500 polychaete larvae have been found per square metre of sea ice in the innermost parts of Van Mijenfjorden. Whether these represent one species or several is currently under taxonomical and molecular analyses.

In 2015, we discovered two cnidarians in the bottom 10 cm of sea ice in Van Mijenfjorden. Now, molecular analyses have confirmed our morphological identification of one of these cnidarians as the hydrozoan *Sympagohydra tuuli* - the first ever recorded in the Svalbard archipelago. This ice-living hydroid was first discovered in Barrow (Alaska) in 2003. In 2008, it was recognised as a new species, and shortly after, it was found in both fast ice and pack ice in the Western Canadian Arctic and in the Central Arctic Ocean. This small (0.2 to 1.1 mm) hydroid has a unique combination of characteristics that distinguish it from other known hydroids. It is therefore assigned to a new family Sympagohydridia under the hydrozoan subclass Hydroidolina, order Anthomedusae, suborder Capitata. The genus name *Sympagohydra* was chosen because it is an ice-associated (=sympagic) hydroid, while its specific name was in honour of Tuuli, the newborn daughter of Bodil Bluhm and Rolf Gradinger, who first discovered this species. Bodil and Rolf recently moved to Tromsø where they work as professors at UiT The Arctic University of Norway. This is very fortunate for the Fram Centre institutions and today UiT, UNIS, the Norwegian Polar Institute and Akvaplan-niva collaborate closely to expand knowledge on sea ice meiofauna in the European Arctic.

WHAT WE KNOW ABOUT *SYMPAGOHYDRA TUULI*

The finding of *Sympagohydra tuuli* in Svalbard, European Arctic, is important as it confirms the circumpolar distribution of this species. Still little is known about its life cycle. Its presence in coastal sea ice over shallow depths suggests a bentho-sympagic life strategy (alternating between seabed and sea ice). However, the findings of reproducing *S. tuuli* in sea ice in the central deep (>3000 m) Arctic Ocean, combined with its high tolerance to changing temperature and salinity suggest that it is an autochthonous sympagic

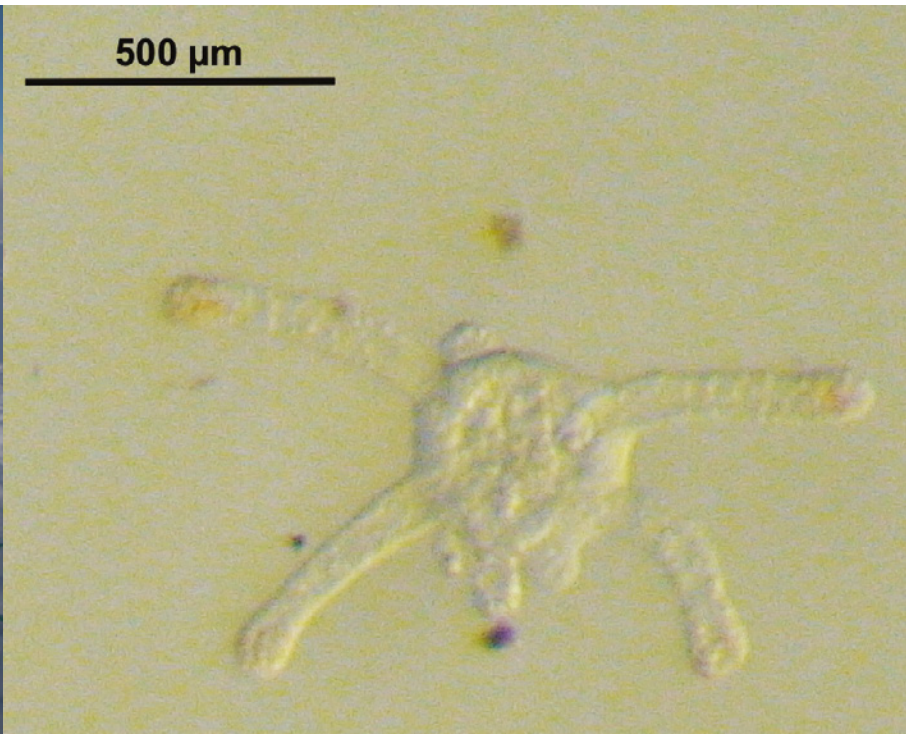


Photo: M Marquardt

PROJECT INFORMATION

This study was supported by the Fram Centre incentive fund (Project EcoCice, RiS no. 10612), an Arctic Field Grant (RiS no. 10641 for V. Pitsui) and the Norwegian Biodiversity Information Centre project GooseAlien (47-15, 70184235 for S. Majaneva).

species (which means it is native to the ice and lives its entire life there). Still, the occurrence of *S. tuuli* in seasonal fast ice in western Svalbard with no direct connection to the multiyear ice pack of the Arctic Ocean challenges this latter theory. A sympago-pelagic life strategy cannot be ruled out either, due to records of this species in the open water just below newly forming sea ice in the deep Central Arctic Ocean.

Sympagic meiofauna mainly graze on ice algae, but they may also feed on the rich and diverse microbial community that exists in sea ice. Direct evidence of predatory sympagic meiofauna did not exist until it was demonstrated that *S. tuuli* preys upon copepod nauplii of almost the same size as itself. Moreover, the few records of cnidarians in sea ice may not be representative of their true numbers. Most analyses of sea ice meiofauna have been conducted on preserved samples in which several meiofaunal taxa, gelatinous zooplankton in particular, are known to be poorly preserved. Consequently, this cnidarian may have been unrecognised or simply overlooked, as it is rather small and nearly transparent. The ecological role of *S. tuuli* in the sympagic ecosystem may thus be significant even if the species appears to be rare judging from the data we have to date.

PLANS FOR 2018

Preliminary data indicate greater sympagic meiofauna biodiversity in eastern than in western Svalbard. In 2018, we therefore aim to follow the seasonal development of the meiofauna community in Storfjorden, eastern Svalbard, in cooperation with the Norwegian Polar Institute. They have been monitoring sea ice there since 2007, but so far they have focused on physics and not on sea ice biota! ■

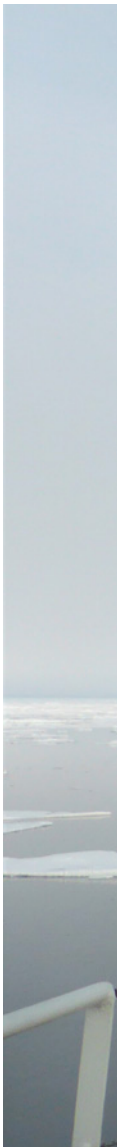
FURTHER READING:

Marquardt M, Majaneva S, Pitusi V, Søreide JE (2017) Pan-Arctic distribution of the hydrozoan *Sympagohydra tuuli*? First record in sea ice from Svalbard (European Arctic). Polar Biology. https://doi.org/10.1007/s00300-017-2219-8

Maaike Knol and Peter Arbo // UiT the Arctic University of Norway
Sebastian Gerland, Olga Pavlova and Stein Tronstad // Norwegian Polar Institute
Machiel Lamers // Wageningen University
Anders Doksæter Sivle // Norwegian Meteorological Institute

Arctic weather and sea ice information infrastructures: dynamics and drivers

In ArcticInfo a team of social scientists, meteorologists and sea ice experts study the development of infrastructures to monitor weather and sea ice to get a better sense of how these systems might affect economic decision-making and potentially alter the marine Arctic as a zone of risk.



On one hand, the Arctic is depicted as the last frontier: a region of opportunities, which will become more accessible due to receding sea ice. On the other, it is portrayed as a vulnerable region in need of preservation, with growing concerns about the effects of climate change and its consequences for ecosystems and human living conditions. Both images trigger efforts to improve mapping, surveying and monitoring capabilities in the Arctic. Focusing on weather and sea ice information services, ArcticInfo aims to enhance knowledge about the development of such information infrastructures and to understand how they can affect economic decision-making and alter the Arctic as a zone of risk. ArcticInfo will also generate knowledge about the user-producer interface in weather and sea ice information provisioning, which can be used as input to strengthen interaction and communication between forecast providers and users.

NETWORKED INFORMATION PROVISIONING

Information about weather and sea ice conditions in the Arctic is created, delivered and utilised in complex networks in which many actors take part. The main providers of operational meteorological information are the national meteorological services (NMS) and the national ice services. While these entities produce large amounts of data through a variety of observation technologies, they also depend on external actors such as space agencies, ships, aircraft, and others who provide regular observations. Over the last decades,

new weather and sea-ice information services have been developed at scales from international and pan-Arctic to national or even local. In the first phase of the ArcticInfo project, we studied several such initiatives to learn more about the drivers and dynamics of information provisioning in the Arctic (see text box on page 53 for examples).

DRIVING FORCES

We identified four main driving forces behind the establishment of collaborative information platforms. First, advances in information and communication technology, including satellite technology, lay the basis for new services. Second, the desire to overcome the huge challenges of data management and data sharing prompts establishment of new platforms. A third factor is the expected need for service improvements such as more frequent updates, higher resolution sea ice charts, or improved extreme weather alerts. A fourth driver relates to problems of access to data in the remote Arctic, with low bandwidth and unreliable connections.

DYNAMICS OF INFORMATION INFRASTRUCTURES

The information platforms we have studied have a highly networked character. The NMS continue to play key roles, in particular in delivering operational services to end users. Most of these platforms have emerged through project funding, leaving them vulnerable to funding discontinuity. BarentsWatch is an interesting exception. Some of the private or public-private platforms, like Polar View, charge fees for the use of services on a non-profit basis. Revenues are used to improve or develop new services. In general, open data sharing is strongly emphasised.

Helicopter operations.
Photo: Sebastian Gerland / Norwegian Polar Institute

Vessel and sea ice. *Photo: Sebastian Gerland / Norwegian Polar Institute*

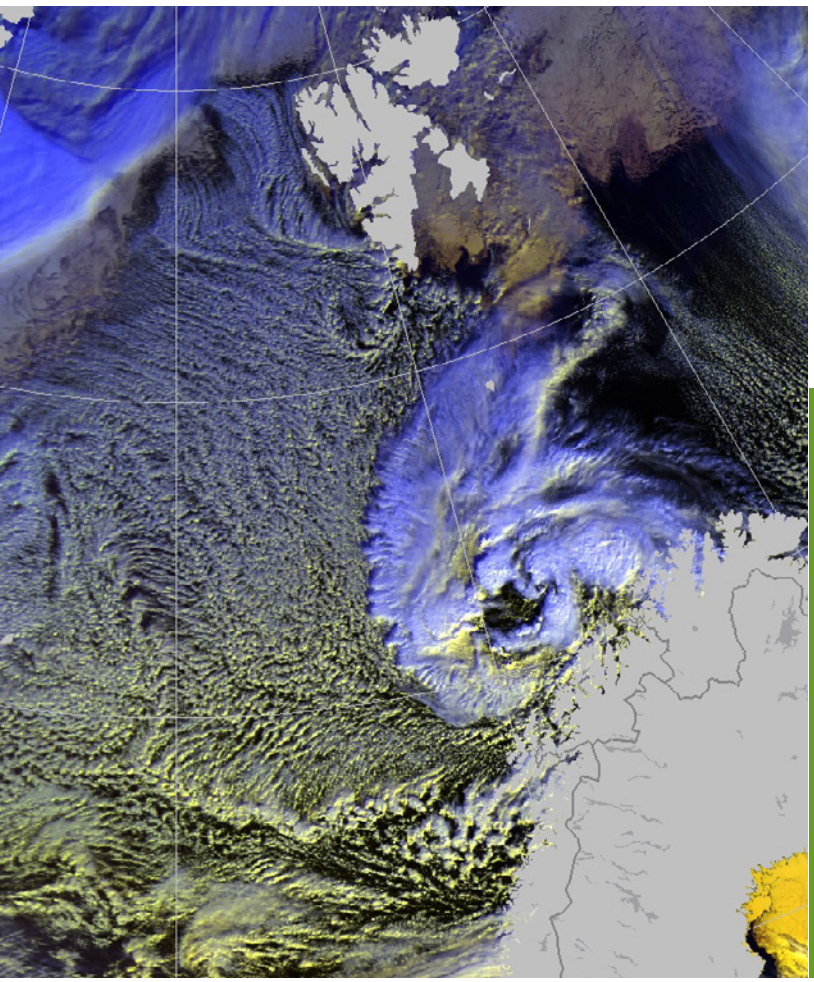
CHALLENGES AND PARADOXES LIE AHEAD

In the development of information services for marine arctic areas, there is an inherent tension between standardisation and flexibility. Standardisation is required to provide consistent services, to enhance interoperability between systems and organisations, and to support coordination. On the other hand, the infrastructures need to be flexible to respond to changing situations, expectations and needs.

Improved information services allow for better-informed decision-making. Consequently, information infrastructures mitigate risk. However, they also introduce new risks by allowing further expansion of activities and enhancing the users' dependence on technologies in remote areas where other infrastructures do not develop at the same pace (such as Search and Rescue).

To become functional and durable, arctic information infrastructures need to build on robust and up-to-date technical and scientific components. However, they are inherently social as well, and their socially networked character is as vital for their long-term success as their technical functionality.

To improve our understanding of the workings of arctic information infrastructures, more research is needed into the user-producer interface. What are specific users' needs and how are they - or can they be - involved in co-designing the information services? Follow-up research will uncover the potential for more user-friendly and salient information provisioning in the Arctic. ■



"Information systems for the Arctic Ocean: architecture, drivers and effects on marine economic activities" (ArcticInfo) is an interdisciplinary project funded by the Fram Centre (Arctic Ocean Flagship) with participants from UiT The Arctic University of Norway, the Norwegian Polar Institute, the Norwegian Meteorological Institute and Wageningen University (The Netherlands).

Satellite image of a Polar Low. *Copyright NOAA*

BarentsWatch (www.barentswatch.no/en) coordinates and disseminates information to provide a comprehensive picture of activities in and conditions of the Norwegian ocean and coastal areas and beyond. It includes warning services for Polar Lows and wave heights, and interactive mapping tools. BarentsWatch is funded by the Norwegian government and run by the Norwegian Coastal Administration.

Arctic Web (https://arcticweb.e-navigation.net) is run by the Danish Maritime Authority and provides eNavigation functionalities for safe navigation in Danish Arctic waters. It includes tailored ice charts and weather forecasts based on a vessel's position and planned route. It can deliver information about other ships in the area and nearby Search and Rescue resources.

Polar View (www.polarview.org) was initiated as an international collaborative project with the aim to improve ice services, and to coordinate and provide integrated monitoring and forecasting services in polar areas. It delivers satellite-based information services to support economic activities, resource and risk management, as well as maritime operations. When the project funding ran out in 2011, Polar View transitioned into a corporation.

Trude Borch // Akvaplan-niva

The GLIDER project – Unmanned Ocean Exploration

BUSINESS DEVELOPMENT AND OCEAN MANAGEMENT

Accurate and up-to-date information about the ocean's biological and oceanographic conditions is important for utilising ocean resources in an efficient and sustainable way. Businesses and environmental managers are seeking access to high-quality ocean data, also from more remote areas of the ocean. Traditional approaches for collecting environmental data with research vessels are costly and require significant investment in labour and equipment. Therefore, scientists are now testing unmanned ocean vehicles ("gliders"), equipped with a range of sensors, as a cost-effective way to collect large data sets over vast areas of the ocean. Gliders can collect data from both the ocean surface and deeper in the water column, and are intended as a supplement to data harvest from research vessels, not a replacement.

THE TECHNOLOGY

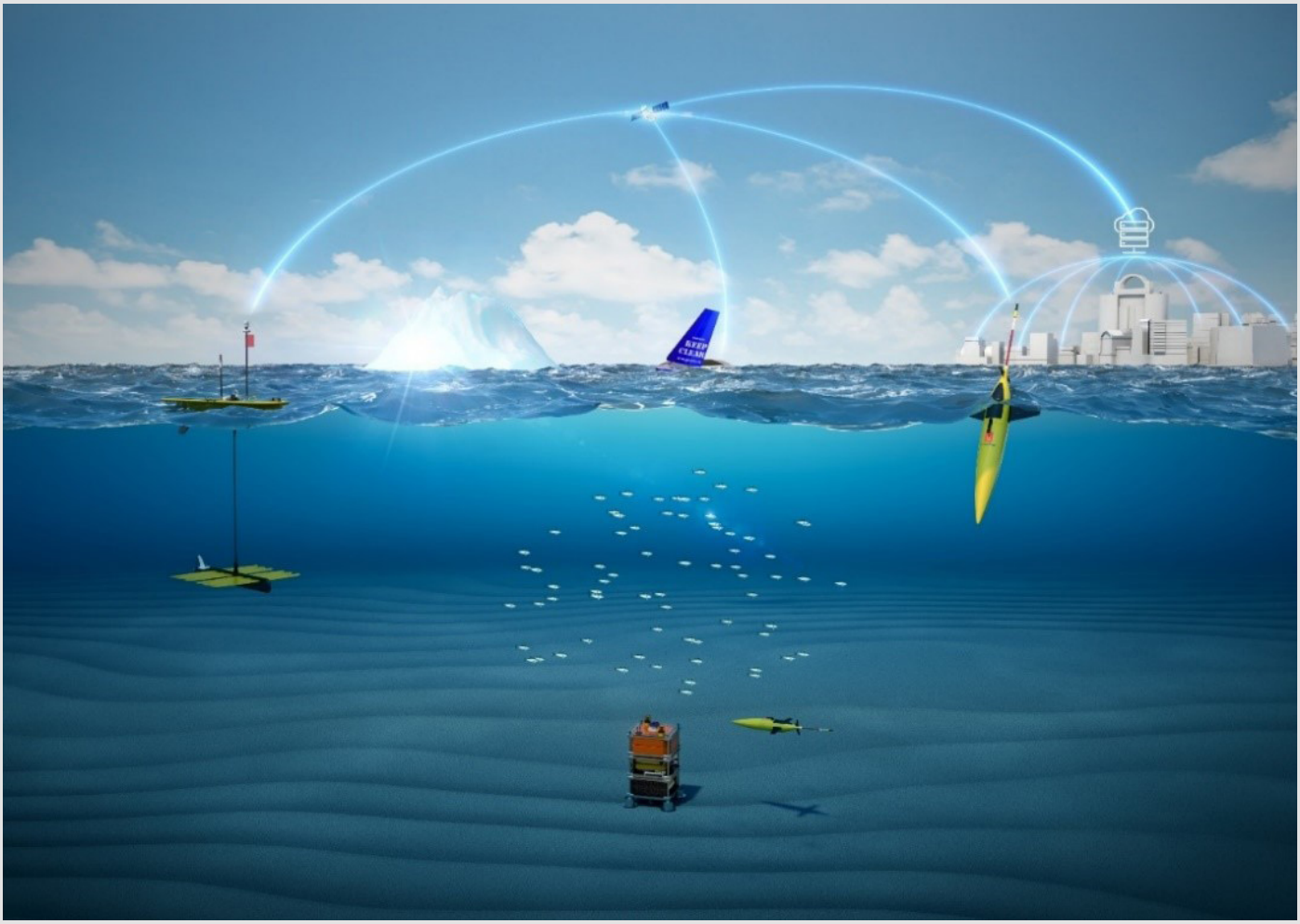
The GLIDER Project's vehicles are a diving Seaglider™ (produced by Kongsberg Maritime AS), a Sailbuoy (produced by Offshore Sensing AS) and a Wave Glider (operated by Maritime Robotics AS). The gliders are energy-efficient, taking advantage of energy from waves, wind and solar power. They are equipped with GPS communication devices for real-time piloting from a home PC. They follow pre-programmed routes and depths, but can also easily be re-programmed from land. Each vehicle carries a variety of sensors for the collection of chemical, physical and biological ocean and atmospheric data. The sensors provide continuous measurements of weather, waves, currents, temperature, salinity, O_2, CO_2, pH, ocean acidification, marine algae, animal plankton, fish fry and marine mammals. The data can be stored on board the vehicles or sent via satellite to the base station onshore. An e-platform allows real time data visualisation and interpretation.

TECHNOLOGY TESTING

During late summer 2017, the project consortium pilot tested the three unmanned vehicles; the gliders were deployed 1 August outside Sandnessjøen and retrieved 7 September outside Bodø. The mission was successful despite two periods of marginal weather with average wave heights in excess of 6 metres. Over these 35 days, the vehicles travelled a total of 4 500 kilometres. In 2018, they will be deployed continuously from March through September.

TAILOR-MADE ANALYSIS: A DIGITAL OCEAN

The collected data will contribute to a better understanding of the structure and function of marine ecosystems and improve our existing ecological, oceanographic and meteorological models. The goal of this project is to offer baseline information for decision-making to support profitable ocean businesses and sound ocean management. The deliverables include both short- and long-term as well as time-series data. The project will develop a system for distribution and management of data. This will ensure that data can be tailored for government



agencies and R&D institutions, as well as ocean industries such as shipping, oil and gas, aquaculture, fisheries, offshore mining and tourism.

PARTNERS

The GLIDER project is led by Akvaplan-niva, Tromsø, and financed by the Research Council of Norway DEMO2000 program and ConocoPhillips Scandinavia. The partners in the project are the Norwegian Meteorological Institute, the Norwegian Institute for Water Research, UiT The Arctic University of Norway, Nord University, Kongsberg Maritime AS, SIMRAD, Maritime Robotics AS, Offshore Sensing AS, Christian Michelsen Research AS, and Aanderaa Data Instruments AS. ■

GLIDER
Unmanned Ocean Exploration

FOR MORE INFORMATION CONTACT:

Lionel Camus, Project coordinator:
Phone +47 95943255
Email: lca@akvaplan.niva.no

Salve Dahle, Project owner:
Phone +47 90649490
Email: sda@akvaplan.niva.no

Amanda Poste // Norwegian Institute for Water Research

Where river meets fjord

The land-ocean interface, where land meets sea, is a dynamic environment that supports productive coastal ecosystems. These, in turn, are a key source of marine resources for northern communities. But northern coastal ecosystems are in transition.

Adventelva flowing into Adventfjorden, Svalbard.
Photo: Uta Brandt

Multiple stressors, often inter-related, are exerting pressure and driving long-term environmental change in coastal environments. Stressors such as climate change (e.g. alterations in precipitation and runoff patterns, shifts in catchment vegetation) and land-use changes can lead to changes in the movement of water, sediments, nutrients, organic matter and contaminants from land to sea. These changes may have strong effects on coastal water chemistry, ecology and cycling of contaminants such as mercury.

However, very little is known about the downstream effects of terrestrial inputs on coastal ecosystems, and without comprehensive baseline knowledge on the nature and magnitude of these inputs and their biogeochemical and ecological consequences, it is difficult to assess how future increases in these inputs might affect northern coastal ecosystems.

RIVER INPUT EFFECTS ON SUB-ARCTIC FJORDS

Our recent work has focused on exploring how riverine inputs affect the biogeochemistry, ecology, and mercury contamination of northern fjord ecosystems. Through detailed fieldwork, sampling on six occasions from August 2015 to November 2016, we have characterised physicochemical conditions, pelagic lower food web ecology and mercury dynamics along a freshwater to marine gradient in a sub-Arctic Norwegian river-fjord system (Målselv-Målselvfjord, in Troms).

EFFECTS ON PHYSICOCHEMICAL CONDITIONS

Physical and chemical conditions in the river-fjord system were primarily driven by mixing of the fresh and marine water masses, and were strongly influenced by recent rainfall and river discharge. The influence of freshwater inputs from the river extended well beyond the outer fjord during periods of high river flow, while during periods of low river flow, only a thin layer of fresh or brackish water was present in the inner fjord. In all seasons, the river was a source of terrestrial organic matter, silicate and mercury to the fjord ecosystem.

FJORD ZOOPLANKTON RELY ON FOOD FROM LAND

Stable isotopes of carbon are often used to determine where organisms get their nourishment, as different primary carbon sources often have different isotopic composition. The strong contrast between the stable carbon isotopic values of riverine and marine-derived organic matter allowed us to use a two-source mixing model to assess the relative importance of terrestrial (riverine) versus marine energy sources for fjord zooplankton.

Nearshore zooplankton appeared to rely heavily on terrestrial inputs as a food source, especially when river flow had been high in the weeks and months prior to sampling. The importance of terrestrial energy sources tended to decrease with increasing distance from the river outflow. This suggests that riverine inputs can represent an important source of external energy to coastal plankton communities.

RIVERINE INPUT INCREASES MERCURY LEVELS

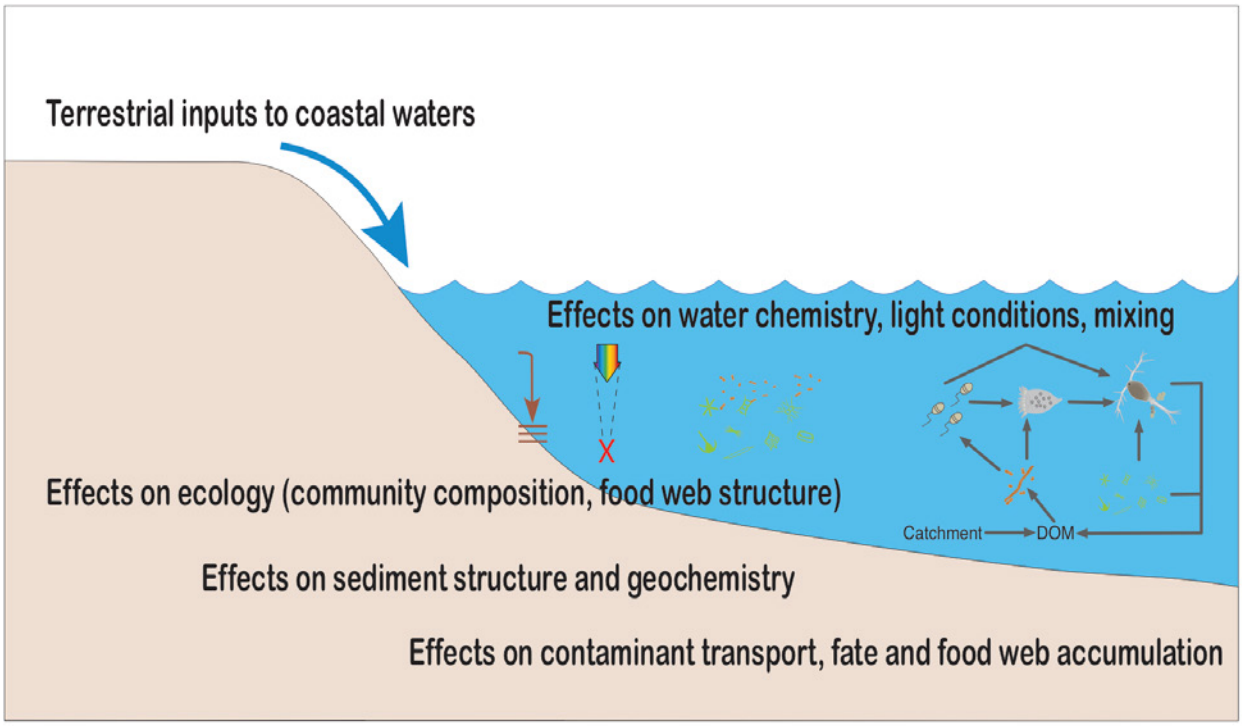
The river was an important source of total mercury to the fjord, with some evidence of mercury methylation in the fjord. Both total mercury and methyl mercury concentrations in zooplankton decreased from the inner to the outer fjord. Bioaccumulation factors (the ratio between concentrations in zooplankton and concentrations in water) were higher in the inner fjord, suggesting more efficient food web accumulation of mercury at sites with higher freshwater influence.

These results highlight the potentially strong impact of riverine input on coastal biogeochemistry, ecology and mercury contamination. A paired study in a southern Norwegian river-fjord system (Storelva-Sandnesfjord) gave similar results. We are now doing follow-up studies in both river-fjord systems focusing on how terrestrial inputs affect sediment geochemistry, benthic ecology, and contamination of benthic organisms.

NEXT STEPS: MOVING NORTHWARD

We are now expanding this work to Svalbard, where in addition to changes in precipitation and runoff patterns, thawing permafrost and melting glaciers can be expected to alter the mobilisation and transport of water, sediments and associated compounds from land to sea. The highly interdisciplinary TerrACE project (see fact box) will provide detailed information on: the nature and magnitude of terrestrial inputs to Svalbard's coastal waters; physicochemical conditions across gradients in the influence of terrestrial inputs; and effects of terrestrial inputs on the flow of energy and contaminants (including mercury and PCBs) into and through Svalbard's coastal food webs.

Through a combination of field-based and modelling approaches, our work in the TerrACE project, as well as in our previous work in mainland Norwegian river-fjord systems, aims to characterise the complex interplay between terrestrial inputs to coastal waters and coastal biogeochemistry, ecology and pollution, and to provide critical baseline information for understanding how future changes in these inputs may affect northern fjord ecosystems. ■



Conceptual framework for how terrestrial inputs can affect coastal biogeochemistry, ecology and contaminant dynamics. DOM = dissolved organic matter

Collecting a zooplankton sample in Målselvfjord.
Photo: Guttorm Christensen

Working with students from a school in Bardufoss to filter river water samples from Målselv.
Photo: Siri Beate Arntzen

THE PROJECTS

The work in Målselv–Målselvfjord was funded by the Fram Centre's Hazardous Substances Flagship and the Norwegian Institute for Water Research's strategic institute programme for land-ocean interactions.

The TerrACE project ("Where land meets sea: Effects of terrestrial inputs on Arctic coastal ecosystems") is funded by the Research Council of Norway.

These projects involve a large interdisciplinary team of researchers from Norwegian and international institutes.

COLLABORATORS

Maeve McGovern, Anders Ruus, Hans Fredrik Veiteberg Braaten, Ian Allan, Øyvind Kaste, Pernilla Carlsson:
Norwegian Institute for Water Research

Guttorm Christensen, Paul Renaud, Anita Evenset, Eva Leu:
Akvaplan-niva

Katrine Borgå, Sabrina Schultze:
University of Oslo

Lena Seuthe:
UiT The Arctic University of Norway

Sebastiaan Koppelle:
University of Amsterdam

Øystein Varpe, Janne Søreide:
The University Centre in Svalbard

Kjersti Tønnessen Busch, Siri Beate Arntzen:
SALT (salt.nu)

Michael Arts:
Ryerson University, Canada

Ken Dunton:
University of Texas Marine Sciences Institute, USA

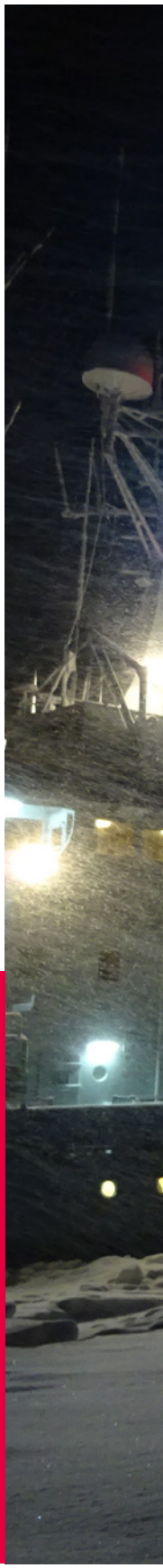
Mats Granskog and Harald Steen // Norwegian Polar Institute

Sea-ice system in the Atlantic sector of the Arctic Ocean – a stormy tale

We stand in inky polar darkness on an ice floe in the Arctic Ocean, far from land, a kilometre of seawater under us. Scientific instruments dot the ice, collecting data and taking samples. As we approach one, a crack opens up in the ice. Cold water churns at our feet. What do we do? We play it cool!

THE TEAM on the Norwegian young sea ICE expedition (N-ICE2015) endured challenging conditions to study the drastically thinning sea ice in the Arctic Ocean. We spent nearly six months in the mobile ice pack north of Svalbard, from the polar night in January to the onset of summer melt in June of 2015. Our base, the research vessel *Lance*, was moored to a series of ice floes. We were battered by several storms that brought fierce winds, snow, and warm temperatures in the midst of winter. Meteorologists call these horrific storms arctic cyclones, but we counted ourselves lucky when they came, because they taught us so much.

The storms repeatedly wreaked havoc by breaking up the ice floes under our feet. At the end of the campaign in June, the large ice floe with our equipment broke up into hundreds of small floes, with some of



RV Lance lies frozen into the ice in the darkness of winter, weathering one of the storms that brought heavy snowfall and significantly warmer air. *Lance* was our home and our reliable companion in the ice. Despite her age, she withstood the challenge, which for many of us was the experience of a lifetime. N-ICE2015 was the last tick in her bucket list, as she is now leaving the Norwegian Polar Institute. Needless to say, we wish her all the best in her retirement. *Photo: Mats Granskog / Norwegian Polar Institute*

We were surprised at the amount of snow we found lying on top of the sea ice.
Photo: Tor Ivan Karlsen / Norwegian Polar Institute

our invaluable instruments balancing on small pieces of ice, barely staying afloat. But we played it cool. We had been through ice floe break-ups earlier in the year and were confident we could pull it off once again. And pull it off we did: not a single instrument was lost.

Now, three years later, we have had time to look at all the data we collected; we have new insights and a deeper understanding of how the sea-ice system in this part of the Arctic functions. We have also had time to dig into other data to place our unique observations in context. What emerges is that no single region of the Arctic is representative of the Arctic as a whole, and the frequent storms that travel from the Atlantic and all the way into the Central Arctic are a key feature affecting the sea-ice system in the Atlantic sector. In this part of the Arctic, the inflow of relatively warm Atlantic water is also of significance, but its effect is modified by storms, which bring energy that moves the ocean heat at depth to the surface. Our work suggests that in the Atlantic sector, both the number of storms and their duration have increased.

Our direct observations during several severe winter storms are a unique glimpse into how the sea-ice system responds to these short-lived but intense events. A severe storm broke up the ice in early February and although the ice refroze, it never regained its strength: storms leave a legacy that endures long after they have passed.

What surprised us, from the outset, was the amount of snow on the sea ice. Snow depths near half a metre were the norm rather than the exception. In hindsight, we know that atmospheric patterns favoured transport of moisture and thus accumulation of snow on the sea ice in the areas north of Svalbard and the Barents Sea. Again storms play a key role, as most precipitation (snow) is deposited during storms. Our work suggests that these conditions may actually be typical in this part of the Arctic; we simply hadn't been out there before to observe what is normal. Despite the amount of human activity around Svalbard, surprisingly few observations have been made in this region, especially in winter.

Once snow has accumulated, sea ice growth is limited and occurs much more effectively in locations with open water - leads. Again, passing cyclones provide energy to move the ice around, creating such openings in the ice pack. And the thinner the ice gets, the more susceptible it will be to storms. On one hand,

People rescuing equipment after the ice breakup in June.
Photos: Mats Granskog / Norwegian Polar Institute

storms deposit snow that limits sea-ice growth, but on the other hand, they create opportunities for new ice to grow in open leads. Understanding how these opposing forces balance out is an important future task.

In addition, the storms increase mixing in the ocean, bringing more heat to the surface. Warm Atlantic water that is brought up from the depths impedes sea ice growth; in extreme cases it can even melt the ice, even if the air is at –30°C and ice would normally grow.

Together, these mechanisms create conditions that prevent the ice from growing thick. As the ice gets thinner it is also more vulnerable to the storms: it is weaker; it breaks up and moves around, again increasing mixing in the ocean. In the summer that follows, the ice is more likely to melt away completely. In fact, areas of open water created during storms in the ice pack are hotspots for exchange between atmosphere and ocean.

The increased mixing during the storms also affects the fluxes of nutrients and other seawater constituents from depth to the surface layer, and could be important in pre-conditioning the system for spring, when the sun returns, and primary producers get going. We experienced an early under-ice phytoplankton bloom; it came far earlier than we had imagined, when the ice was still thickly covered with snow. The mobile ice pack created openings in the ice, windows that let sunlight into the ocean and allowed phytoplankton to grow.

The changing ice pack also seems to be creating new spaces for ice algae to thrive. When the heavy snow load submerges the surface of the ice, the undermost layer of snow can be flooded with seawater. Thriving algae can make these slushy habitats look like brown soup. This phenomenon is widespread in the Antarctic but has not previously been observed much in the Arctic.

Overall, we find that the sea-ice system in the Arctic is in transition: where there used to be a lot of old thick ice, we are now beginning to see something more like the seasonal sea-ice system in the Southern Ocean. ■

FURTHER READING:

www.npolar.no/nice2015

Robert M. Graham // Norwegian Polar Institute

Increasing frequency and duration of arctic winter warming events

The Arctic is warming much faster than any other region on the planet. This warming is not spread evenly throughout the year, but is concentrated in the cold autumn and winter months, when mean temperatures for this region are below -30˚C. Autumn and winter is when arctic sea ice grows thicker.

Warmer winter air temperatures can slow down ice growth and expansion, accelerating the effects of global warming in the Arctic. In recent years, this has been indicated by low sea ice extent at the end of the season. In March 2017 the extent was the lowest since the start of satellite observations, beating the previous record from March 2015 and 2016.

On 31 December 2015, scientists were shocked to discover that air temperatures near the North Pole were above the melting point. These unseasonable temperatures were first detected by several drifting buoys, which scientists had frozen into the arctic sea ice earlier in the year. The maximum temperature recorded by these buoys was +2.2˚C - the warmest ever recorded in the Central Arctic from December through March, when temperatures usually stay below -30˚C. News agencies around the world were quick to report on these astounding temperatures, and many people assumed that this had not occurred before.

But Norwegian scientists observed something very similar earlier that year. In January 2015, the

A buoy frozen into arctic sea ice. This buoy can measure the air temperature and snow depth, and is the same model that measured record-breaking winter temperatures of +2˚C in the Arctic during December 2015.
Photo: Stefan Hendricks / Alfred-Wegener-Institute

Norwegian Polar Institute's research vessel *Lance*, was frozen into the sea ice at 83˚N and allowed to drift with the ice until June 2015. Between January and March 2015, scientists on board *Lance* observed six major storms. Each storm was associated with a rapid rise in air temperatures. In one case, near-surface air temperatures shot from -35˚C to -2˚C in just 30 hours, before dropping back to below -40˚C. Typically, these "heat waves" lasted no more than one or two days. The warm temperatures are the result of strong winds associated with arctic storms. The winds blow warm, moist air from the Atlantic Ocean northwards into the ice-covered Arctic. However, as quickly as the winds come, they can change direction and blow cold, dry air from the Central Arctic back southwards.

The field observations from 2015 raised several questions. Are these "winter warming events" new to the Arctic? Where in the Arctic do they occur, and how often?

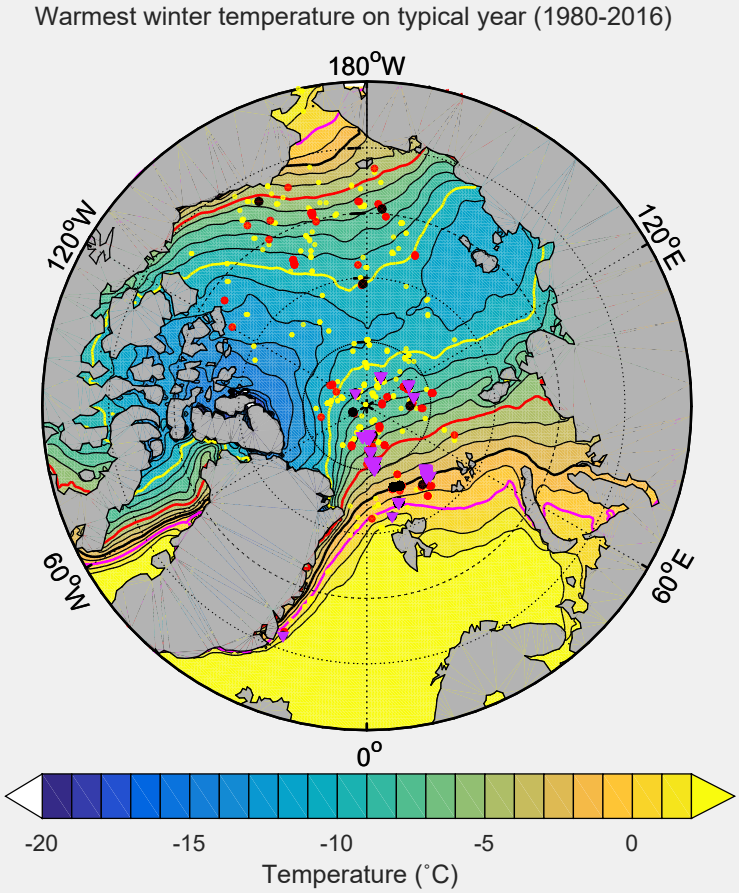
To answer these questions, we looked through historic temperature records from the Arctic. The oldest data we could get our hands on were from Nansen's Fram

The Norwegian Polar Institute's research vessel *Lance*, frozen into the arctic sea ice during the 2015 Norwegian young sea ice campaign (N-ICE2015). In February 2015, air temperatures rose abruptly from -35˚C to -2˚C during a major storm. A few hours later they plummeted to below -40˚C. *Photo: Paul Dodd / Norwegian Polar Institute*

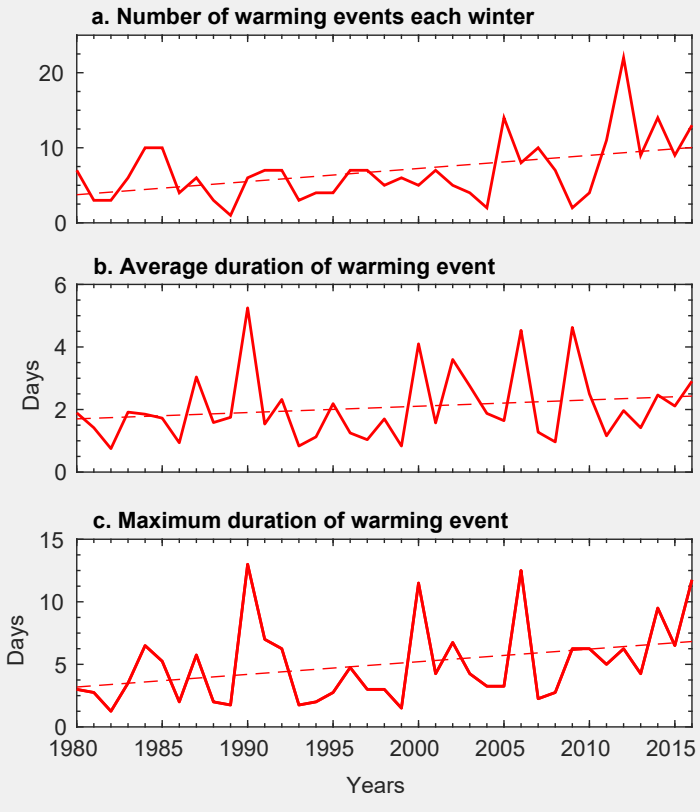
expedition (1893-1896). Remarkably enough, these old records show that temperatures reached -3.7˚C at 84˚N in March 1896. We also analysed temperature records from Soviet North Pole drifting ice stations that were in operation between 1937 and 1991. These logged brief periods with temperatures warmer than -5˚C in approximately one winter of three, and there are several cases where temperatures exceeded -1˚C. These events occur most frequently north of Svalbard and the Bering Strait - the gateways between the Atlantic and Pacific Oceans and the Arctic.

The historic temperature records show that the recent arctic winter warming event in December 2015 was not without precedent. Short periods with temperatures close to the melting point are not uncommon in the Central Arctic during winter. However, the December 2015 event remains the warmest on record.

We further analysed an arctic atmospheric dataset, based on model simulations driven by all available observations that gives our best estimate of the weather at any particular time in the last four decades. These data show that the number of warming events that occur in the Arctic each year is increasing. This increase is largest in the area north of Svalbard and around the North Pole. Moreover, each warming event lasts longer and the peak temperature during each warming event has increased. These trends are due to an increased storminess in the North Atlantic. ■



The warmest winter temperature during a typical year in the Arctic. Pink contour is the 0°C temperature line, black is -2˚C, red is -5˚C and yellow is -10˚C temperature line. Coloured dots show the location of winter temperature observations measured on site. Yellow dots indicate winter temperatures measured above -10˚C, red -5˚C black -2˚C and pink -1˚C.



Occurrences of winter warming events at the North Pole each year from 1980 to 2015. Warming events are classified as air temperatures above -10˚C.

Fram frozen into arctic sea ice during Fridtjof Nansen's first Fram Expedition (1893-1896). In March 1896 scientists on *Fram* measured the unusually warm arctic winter temperature of -3.7˚C. *Photo: The Fram Museum*

FURTHER READING:

Graham RM, Cohen L, Petty AA, Boisvert LN, Rinke A, Hudson SR, Nicolaus M, Granskog MA (2017) Increasing frequency and duration of Arctic winter warming events. Geophysical Research Letters 44: 6974–6983, doi:10.1002/2017GL073395

Marius Runningen Larsson // Norwegian University of Life Sciences and Capia AS
Eirik Mikkelsen // Nofima

Forecasting arctic shipping

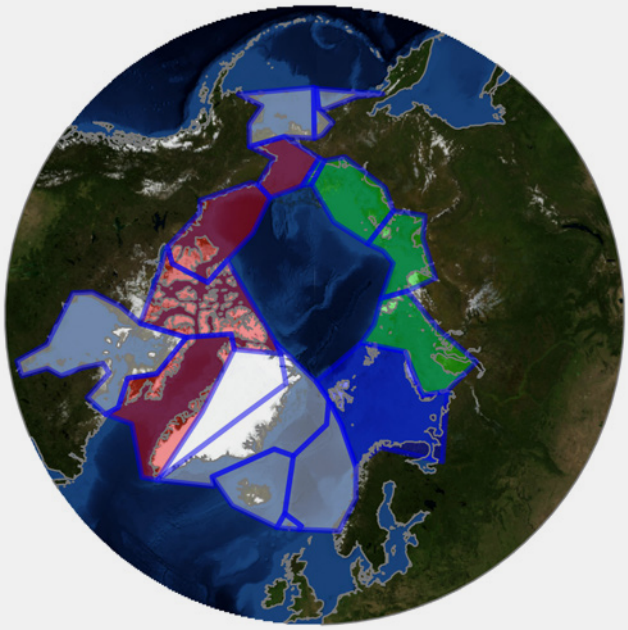
The prospect of increased arctic shipping has drawn much attention in recent years. Commercial interests anticipate a new transit route between the Atlantic and the Pacific. However, shipping in the Arctic is risky, and requires reliable forecasts. We investigate ways to make short- to medium-term forecasts using statistical methods.

The decline of sea ice in the Arctic may open up for new shipping routes over the polar oceans, and render various raw materials in the Arctic more easily accessible. While this development has obvious commercial potential, it also raises concerns for safety and environmental risks, issues related to monitoring and governing the traffic, infrastructure investments, search and rescue capacity and more. Forecasts for arctic shipping are therefore of interest to international bodies, individual states, local authorities, industry, and civil society.

Several analyses have been done on the development of shipping in the Arctic, most of them qualitative studies of possible drivers or scenario exercises, cost and profitability calculations based on engineering or natural sciences, or quantitative studies of ice conditions and the feasibility of sailing. However, the analyses diverge in their predictions of future shipping.

To the best of our knowledge, nobody has previously used statistical analysis of real data to forecast arctic shipping. This is likely because no long time series of actual data about vessels operating in arctic waters have been available until now. With enough data, we can use statistical methods to make short- to medium-term shipping forecasts.

These new data rely on the Automatic Identification System (AIS), a tracking system that most ships are required to use. Ships automatically report their position via satellite or land-based instruments, and the information is stored in databases. Our study is based on data available from the Havbase database (www.havbase.no/havbase_arktis), which is updated monthly and has covered all of the Arctic since 2013. The number of crossings over defined passing lines and distance sailed in different regions is available for 13 different vessel types in 7 different size classes.



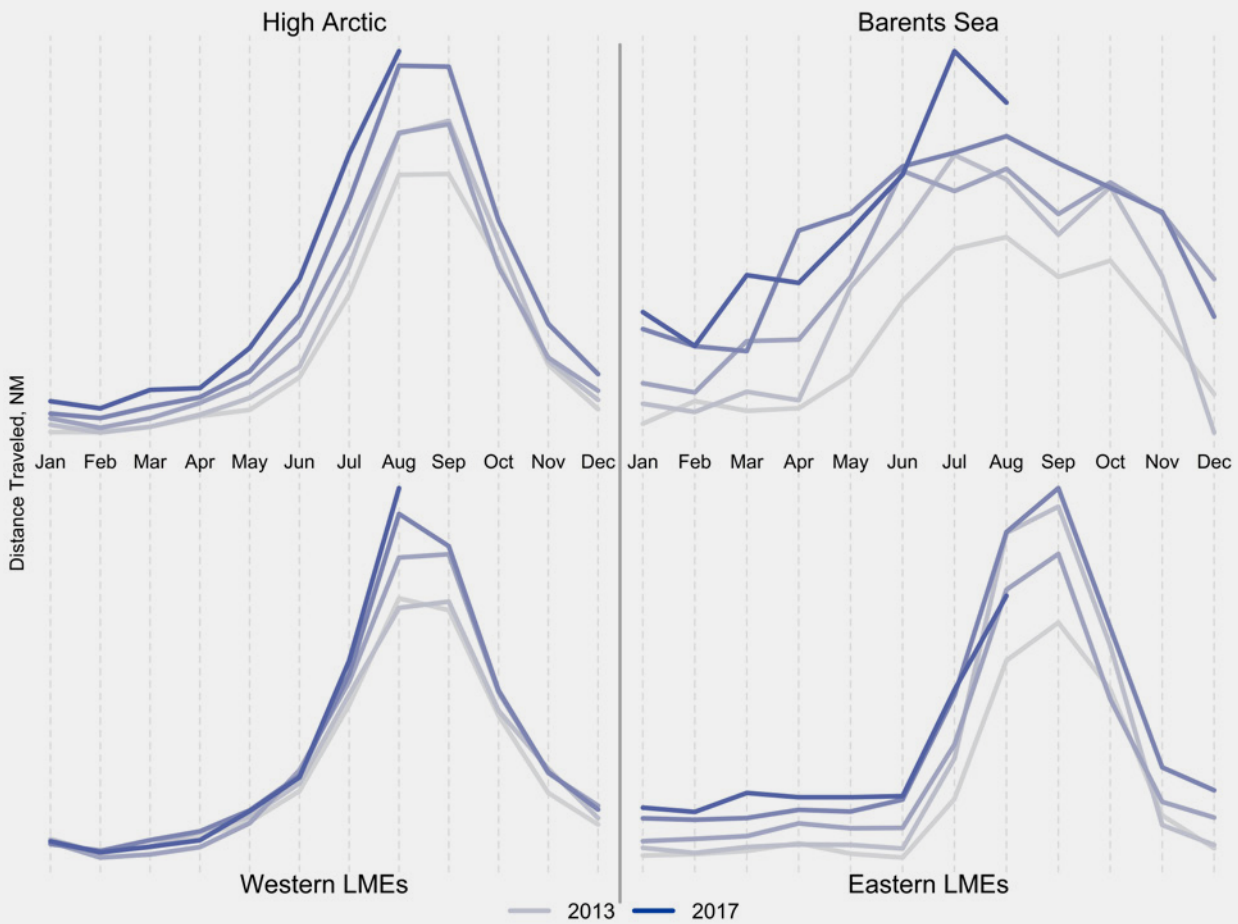
Havbase's Large Marine Ecosystems (outlined in blue) and the areas from which data are aggregated in our forecast models (red – LMEs along the Northwest Passage; green – LMEs along the Northern Sea Route; blue – the Barents Sea LME). The High Arctic series includes data from red and green areas plus the three Bering Sea LMEs, which are not highlighted in this figure. *Background image: NASA Earth Observatory*

The database also lists port calls. The main statistic our study uses is the distance sailed in each of 18 regions denoted Large Marine Ecosystems (LMEs) in Havbase, with data from January 2013 to August 2017.

With 18 LMEs, 13 vessel types and 7 size classes, there could potentially be 1638 time series, but just under 700 series currently include data. We aggregate data from different LMEs to create a "High Arctic" series, which we also split into one aggregated series along the Northwest Passage and one along the Northern Sea Route. The Central Arctic Ocean has no activity registered in Havebase (yet) and is left out. The Barents Sea LME is treated as a standalone area. Within these defined areas, we evaluate various time series characteristics, such as the strength of trends and seasonality, to measure the forecastability of the series. We have noted high seasonality in the traffic pattern and increased forecastability over time as more data accumulate.

We are testing three different forecasting models and an ensemble forecast that combines the three. Traffic data for at least 36 months are used to generate a forecast for the 12 months ahead. We evaluate the models' accuracy by comparing the forecasts with actual data for that period. Then we repeatedly add one more month's worth of data and make a new 12-month forecast. At each iteration, we increment the dataset by one month and shift the forecast period an equal amount until no more data are available for comparison. This procedure gives more robust accuracy measures. The forecasts are also compared against a baseline model - a naïve forecast, which repeats the previous 12 months' observations.

For all the areas evaluated, our forecasting models outperform the naïve forecast. In addition, the ensemble forecasts perform best for three out of the four areas. The mean percentage error of all the forecasts is less than 10% (traffic is underestimated by 8% for the High Arctic, by 0.03% for the Barents Sea, and by less than 2% in the other areas). When the mean percentage error is calculated, over- and under-forecasts cancel each other out, so in absolute values, the errors are naturally higher. Nonetheless, we observe that automated forecasting models can give fairly accurate 12-month forecasts for the Arctic regions we have studied.



The series for indicated areas from January 2013 to August 2017. Shipping is seasonal and is generally increasing over time. The Eastern Series shows a decline in August 2017. The series have different scales on the Y-axes.

Being able to forecast traffic in these areas is of interest in itself. In addition, the results suggest that a hierarchal statistical model can be applied to the entire dataset, which might make forecasts of low-level series more accurate than if they are forecast individually. For example, using aggregated data traffic within an entire LME (high-level) might allow more accurate prediction of vessel types and sizes (low-level). This is because low-level series contain less activity and are more prone to noise.

The traffic data in Havbase may also allow us to identify and assess drivers that can further increase the accuracy of forecasts. This would be particularly useful for longer-term scenario-based predictions. ■

Starrlight Augustine and Jo Lynn Carroll* // Akvaplan niva

Integrating biology into risk assessment models for petroleum industry

Scientists are developing a new generation of risk assessment tools that incorporate key principles from biology, ecology and ecotoxicology to improve existing models for risk assessment. Greater biological realism will help the petroleum industry predict the effects of discharges on key polar species.

During operations, the petroleum industry discharges complex mixtures of chemicals, and inadvertent oil spills are always a possibility. Therefore, models are being developed to quantify risks to organisms that live near discharge sites. Current risk-based methods do not incorporate any knowledge on the biology of exposed species and are heavily reliant on safety factors. This is changing with the advent of biology-based "effects models". Such models combine knowledge about the properties of both chemicals and organisms, and are used to predict how chemicals affect individual organisms. But even that isn't enough. Recent research has shown there can be synergistic or antagonistic effects when organisms are exposed to mixtures of chemicals. Scientists are engaged in developing mathematical solutions to this challenge.

The aim of developing effects models for the industry is to make it possible to follow the links from activity to emissions to effects, such that operators can calculate how their activities relate to expected effects. This requires developing a holistic view of risk assessment: a "Roadmap".

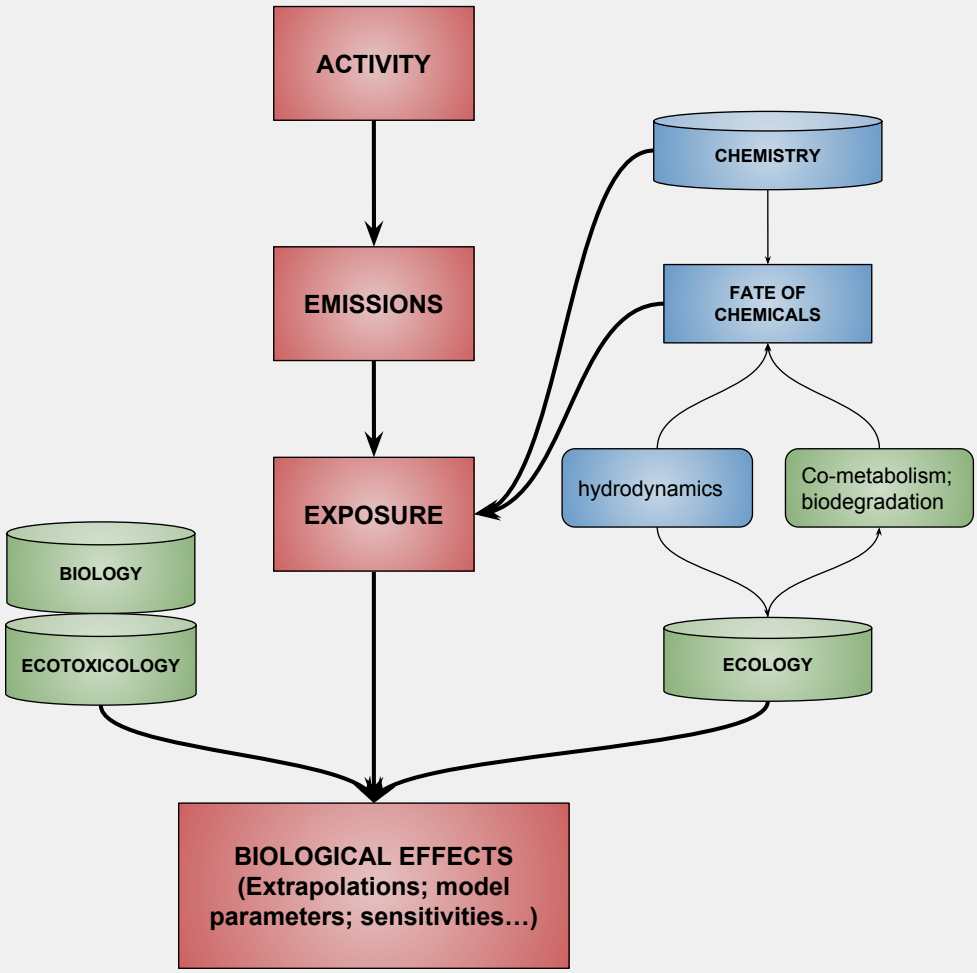
This article gives examples from two R&D projects where scientists are incorporating biological principles into risk assessment tools.

MODELLING POPULATION DYNAMICS

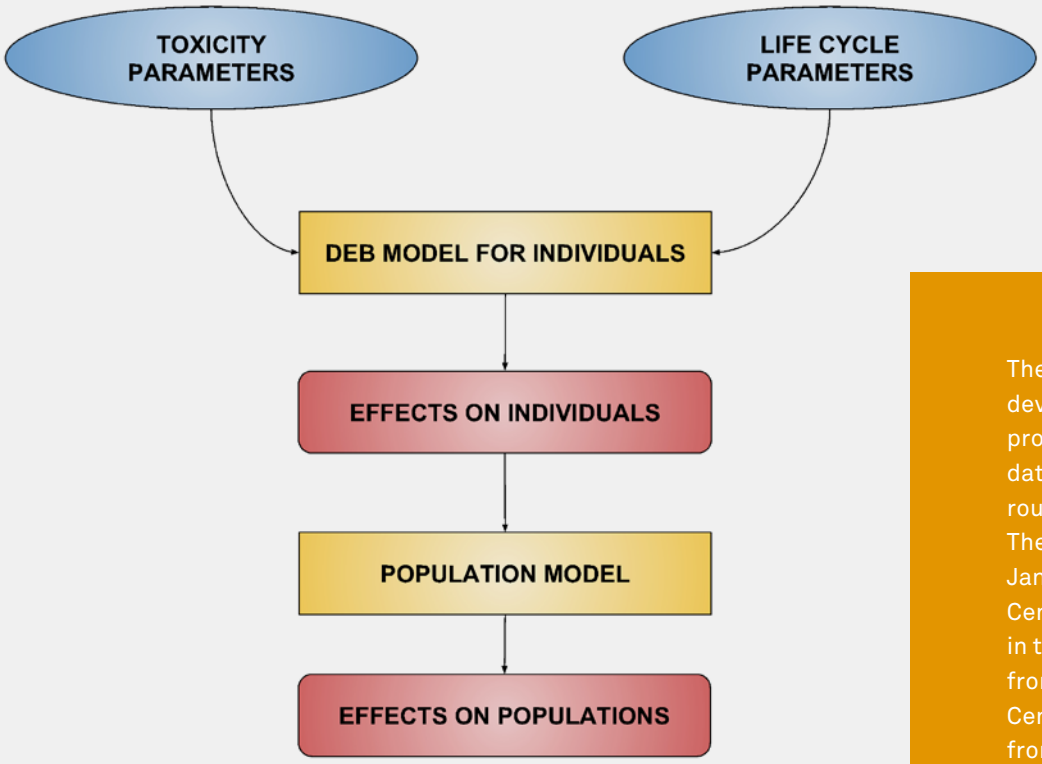
The European Food Security Authority (EFSA) is the key organisation for risk assessment for food and feed safety in the EU. In collaboration with national authorities and stakeholders, EFSA provides independent scientific advice on existing and emerging risks. One of EFSAs main goals is to strengthen the scientific evidence underlying risk assessment and risk monitoring.

Our first R&D example is an effort to develop models of the population dynamics of aquatic and terrestrial organisms based on the Dynamic Energy Budget (DEB) theory, which reasons that although species differ widely, all life has a common foundation in the need to obtain energy to develop, grow and reproduce. DEB theory establishes an extraordinarily simple set of governing rules for these processes, applying the same rules to all life forms from bacteria to whales.

* Also affiliated with UiT The Arctic University of Norway



Roadmap for developing an “effects-based approach” to risk assessment. Biological and ecotoxicological knowledge is incorporated into how effects are calculated. Chemistry, ecology and hydrodynamics are equally important. The effects-based approach is a multi-disciplinary system which combines many different models and requires a large array of expertise. Starrlight Augustine and co-workers are working on biological effects modelling (bottom red box), developing tools for predicting the effects of petroleum industry discharges on key polar species.



The general modelling approach developed during the EFSA project: ellipses represent input data; boxes represent models; rounded boxes represent output. The project was carried out by Jan Baas (project lead) from the Centre for Hydrology and Ecology in the UK, Starrlight Augustine from Akvaplan-niva at the Fram Centre and Gonçalo M. Marques from the Terraprima group, Portugal.

Decades worth of ecotoxicology experiments have shown the myriad effects of mixtures of chemical compounds on the growth, reproduction and survival of exposed organisms. Until now, it has been nearly impossible to determine the "threshold" concentration of a chemical or mixture of chemicals - one that if exceeded will affect biota.

The EFSA project uses DEB theory to integrate knowledge of these biological processes into generic individual and population models that can be used for risk assessment purposes. The scientists developed a toxicity parameter database and free code that allows users to choose any species (in the database) and calculate predicted effects on species survival, growth or reproduction.

This EFSA project developed generic effects models that allow users to calculate the biological effects exposure to mixture of metals, oils and/or pesticides would have on a species. Courses are now being created to teach users how to the code for risk assessment purposes.

OIL SPILLS AND NORTHEAST ARCTIC COD

Much of our understanding of the impacts of oil in the environment on fisheries and the general health of ecosystems comes from detailed post-spill investigations of a few major events (e.g. the Exxon Valdez oil spill in 1989 and the Deepwater Horizon oil spill in 2010). The low frequency, unique circumstances, and complexity of past major oil spills limits their applicability toward predicting the probability of

The next steps in 2018 and 2019 will be to further develop the biological effects model for cod, that is used for simulating effects of oil spills. Another fish species will also be modelled and included in the simulation system. *Photos: Oil platform by night, Pernilla Carlsson. Cod (*Gadus morhua*), Sebastiaan A. L. M. Kooijman*

new spills and developing knowledge that would aid in preventing or minimising damage to biological resources. Models give us a way to examine processes on relevant spatial and temporal scales and to conduct numerical experiments when real experimentation, namely controlled field studies on oil spills, is infeasible. Figuring out how fish populations respond to oil spills requires numerical methods to link biological effects to the toxicity of oil compounds.

The Northeast Arctic cod fishery is sustained through the recruitment of 3-year-olds from spawning grounds mainly in the Lofoten-Vesterålen region - a region currently under consideration for petroleum exploration. In a project funded by the Research Council of Norway, a consortium of Norwegian institutes (Akvaplan-niva, Institute of Marine Research, SINTEF, and UiT The Arctic University of Norway) has been modelling oil spills in the core spawning areas of Northeast Arctic cod. Biological effects are quantified by a subroutine that predicts the survival of individual cod eggs and larvae after exposure to oil compounds. To account for uncertainty in the effects of petroleum compounds on survival, different model parameter sets are applied.

The consortium is now working to extend the utility of the subroutine to include sub-lethal biological effects, such as changes in physiological processes, growth, reproduction and development. This will involve incorporating DEB theory into the current approach. In addition, a new fish species will be introduced into the simulation model. Due to differences in the life history characteristics of fish, we expect that the results on survival of other fish species will differ from the results for cod, which showed that the cod population was resilient to recruitment losses resulting from the simulated oil spills.

Integrating state of the art biological models into the effects side of environmental impact and risk assessment procedures is key to improving environmental risk assessment. State of the art effects-based approaches are a starting point for rational and cost-effective monitoring, and are easier to communicate to stakeholders and the public. ■

Philipp Assmy, Pedro Duarte, Laura Halbach*, Haakon Hop#, Katrine Husum, Hanna M. Kauko, Jack Kohler, Arild Sundfjord, Mikko Vihtakari, Anette Wold and Harald Steen // Norwegian Polar Institute
Elizabeth Jones // Institute of Marine Research
Svein Kristiansen // UiT The Arctic University of Norway
Amanda Poste // Norwegian Institute for Water Research

Tidewater glaciers: role in the marine ecosystem of Kongsfjorden, Svalbard

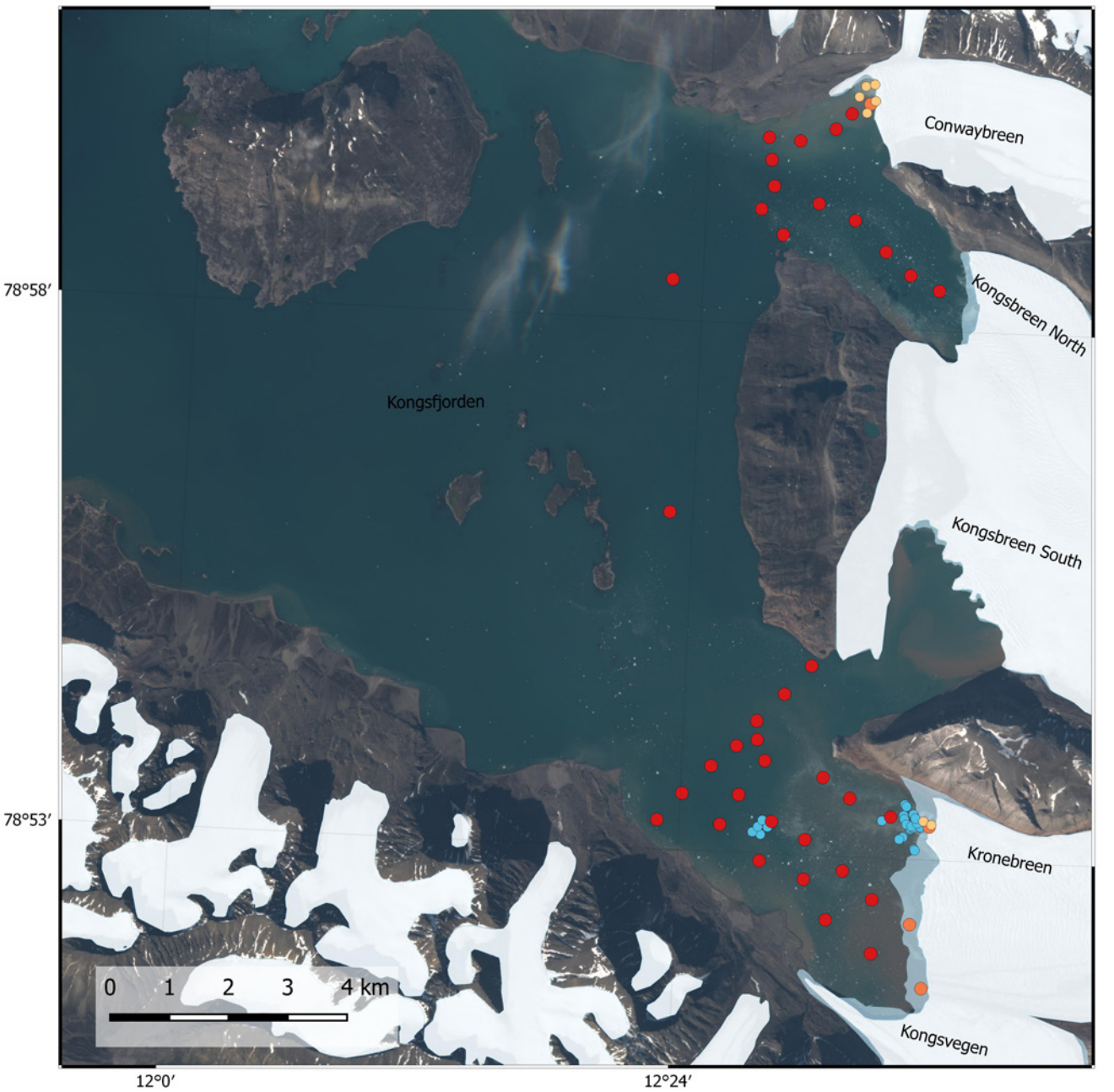
One obvious sign of climate change is rapidly retreating glaciers, not least in Svalbard. We know that loss of glacier ice mass raises sea level, but less is known about how meltwater from Svalbard's tidewater glaciers affects fjord ecosystems, and what might happen if they retreat onto land.

TIDEWATER GLACIERS TERMINATE directly into the sea and have a major influence on circulation in adjacent water masses, particularly in constricted water bodies such as Kongsfjorden in Svalbard. In contrast to meltwater runoff from land-terminating glaciers, which enters the marine environment at the surface via glacial rivers, tidewater glaciers discharge most of the meltwater below the water surface. The low-density freshwater rises rapidly toward the surface near the glacier front and these "meltwater plumes" entrain large volumes of ambient fjord water, typically on the order of 100 times the meltwater discharge volume.

To study the effect of meltwater plumes on the marine ecosystem, we sampled intensively in front of tidewater glaciers in Kongsfjorden in summer 2016 and 2017. Simultaneous water and plankton-net sampling gave us a comprehensive picture of water column properties, phyto- and zooplankton abundances at high spatial resolution in the immediate vicinity of the glacier fronts.

Our results indicate that the meltwater plumes modulate the local fjord environment through effects on the light regime, nutrient dynamics and zooplankton availability for seabirds and fish. Meltwater plumes

* Also affiliated with the University of Gothenburg, Sweden / # Also affiliated with UiT The Arctic University of Norway



Intensive sampling campaign with *RV Lance* and helicopter in front of tidewater glaciers Kongsvegen, Kronebreen, Kongsbreen North and Conwaybreen from 25-28 July 2017. Red dots are *Lance* stations, orange dots helicopter stations, and yellow dots are helicopter casts with the Idronaut CTD probe. Blue dots indicate sampling locations from the campaign in 2016. The grey areas demarcate glacier retreat from 2016 to 2017. *Map: Mikko Vihtakari / Norwegian Polar Institute*

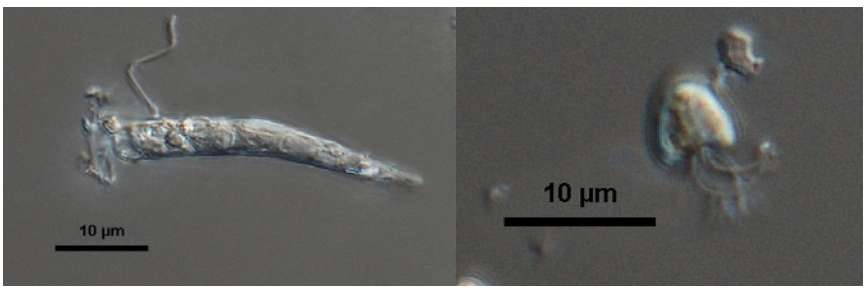
introduce large amounts of glacier-derived sediments into the fjord. These strongly reduce light penetration near the glacier front, but differences in the bedrock at the two fronts create contrasting sediment discharge and, hence, different light regimes. Light quantity and quality were both more favourable for phytoplankton growth at the Conwaybreen/Kongsbreen North glacier front than at the Kongsvegen/Kronebreen front, as reflected by phytoplankton biomass that far exceeded that further out in the fjord. The phytoplankton species composition near the glacier front was also distinctly different and dominated by flagellate algae of the genera *Eutreptiella* and *Pyramimonas*.

Glacier meltwater runoff affects nutrient dynamics in the fjord in two ways. First, the meltwater plume is a direct source of nutrients. Meltwater is enriched in ammonium and silicate through bedrock weathering, as shown by higher concentrations of these nutrients in surface waters near the glacial front. This is supported by 3D fjord model simulations suggesting that ammonium is exported with the glacier water. High ammonium concentrations were measured in pore water from sediment cores taken near the glacial front, suggesting that sediments may also contribute ammonium. Second, the entrainment of ambient fjord water by the rising meltwater plume induces vigorous mixing and a continuous upwelling of nutrients, particularly nitrate, from intermediate depths to the glacier front area. The importance of the upwelling effect will depend on the nutrient concentration at the entrainment depth. In summer, nutrient levels are generally low even at subsurface depths near the glacier front, suggesting that glacier-induced upwelling plays a less prominent role for summer productivity in Kongsfjorden than has been reported for some deeper glacier-influenced fjords in Greenland. However, the rising plume can bring zooplankton and polar cod (*Boreogadus saida*) towards the surface, where they are accessible for surface-feeding birds and also attract marine mammals, predatory fish such as Atlantic cod (*Gadus morhua*) and benthic amphipods that feed on the sinking remnants of the feast.

Our observations support findings from Greenland that fjords with tidewater glaciers sustain an abundant marine life throughout the summer. The actual mechanisms driving this productivity vary depending on position and content of subglacial discharges, fjord circulation and water mass composition. With declining arctic sea ice, the tidewater glaciers in Svalbard have become important foraging hot spots for seabirds and marine mammals, but the hot spots may rapidly diminish when the glaciers retreat onto land. ■

Co-author Anette Wold shows an Atlantic cod caught near the glacier front. Gut content analysis revealed that it had fed on 10 polar cod. Two fresh polar cod caught at the same location are shown for comparison.
Photos: Philipp Assmy / Norwegian Polar Institute

Contrasting suspended sediment load and characteristics in front of Kronebreen (left) and Conwaybreen (right). The higher water transparency in front of Conwaybreen facilitated a phytoplankton bloom there while phytoplankton abundance remained low in front of Kronebreen. *Photos: Laura Halbach / University of Gothenburg*



Phytoplankton species dominating the bloom in front of Conwaybreen: *Eutreptiella* sp. (left) and *Pyramimonas* sp. (right). *Photos: Agnieszka Tatarek / Institute of Oceanology of the Polish Academy of Sciences*

These field campaigns were funded through the Tidewater-ICE project (TW-ICE), Norwegian Polar Institute, with close links to the Polish–Norwegian project Glaciers as Arctic Refugia (GLAERE) and the project Tidewater Glacier Retreat Impact on Fjord circulation and ecosystems (TIGRIF), funded by the Research Council of Norway.

Sediment core taken in front of Kronebreen with characteristic reddish-brown sediment. Pore-water samples for nutrient analysis were extracted at selected depth intervals with syringes. *Photo: Philipp Assmy / Norwegian Polar Institute*

Jon Aars // Norwegian Polar Institute

Population changes in polar bears: protected, but quickly losing habitat

Svalbard's polar bears, which belong to the Barents Sea population, were hunted intensively until their protection in 1973. After that, the population recovered significantly. But in more recent years, sea ice loss in this area has been more severe than in any other polar bear habitat. How are they doing now?

HUNTING, PROTECTION, AND EXPOSURE TO POLLUTANTS

From 1870 to 1973, on average 300 bears were killed or captured live by Norwegians every year, mostly in and around Svalbard. In the 1960s, scientists expressed concern that excessive hunting in the Arctic could threaten polar bear populations. From 1973, Norway stopped all hunting polar bears. Assuming the stock was far below carrying capacity after the intensive hunting, it was no surprise that the population started to recover. By the 1980s, it was believed to have doubled, and demographic data suggested that growth continued to the end of the millennium. In the 1990s, several toxic pollutants from industrial areas were found in polar bear fat, at levels that could potentially affect survival or reproduction.

THE FIRST POPULATION SIZE SURVEY

In August 2004, a large Norwegian-Russian survey estimated that the entire Barents Sea polar bear population numbered 2650. Of these bears, only about a quarter were on the Norwegian side of the border. However, telemetry data show that many bears undertake seasonal migrations. They use the Svalbard area in winter and spring, but migrate northeast to the pack ice and to Franz Josef Land in the western Russian Arctic in summer and autumn. These bears are mostly found not too far north of the sea ice edge. About two thirds of all the bears in 2004 were up in the pack ice, north of Svalbard and north of Franz Josef Land. Only about 250 bears were found in Svalbard, but we attributed this to an unusual sea ice year when the ice edge was far north of the islands.

Polar bears are not at all afraid of water; they will sometimes dive when a helicopter approaches. This bear, an old male, was observed during the survey north of the ice edge in August 2015. *Photo: Jon Aars / Norwegian Polar Institute*

UNUSUAL SEA ICE YEARS–THE NEW NORMAL

In the late 1990s, polar bear researchers used the island of Hopen southeast of Spitsbergen as base for capture-recapture studies in the spring. They observed that in some years, sea ice formed much later than had previously been normal, and that in such years very few females came out of dens with cubs the following spring. This was the start of a dramatic change in the availability of sea ice habitat for polar bears in the Svalbard area. The Arctic as a whole has warmed faster than areas further south, but nowhere have the changes over the last few decades been more profound than in the Barents Sea. The sea ice season is now several months shorter, and the ice edge typically lies several degrees further north than what was normal 20-40 years ago. Hopen is no longer a good

A polar bear visiting the research vessel *Lance* during a cruise north of the ice edge in August 2015. Polar bears are curious, and are often drawn to ships in the otherwise featureless landscape.
Photo: Jon Aars / Norwegian Polar Institute

denning area for pregnant polar bears. Kongsøya, an island some 250 kilometres further north, which has been described as one of the two denning areas in the Arctic with the highest density of maternity dens, probably did not have a single den last spring.

HOW POLAR BEARS MANAGE FAST HABITAT LOSS

In August 2015, a new survey of polar bears in the Barents Sea area was planned with Russian colleagues. Unfortunately, permission to cover Russian areas was never granted. We could therefore only survey the Norwegian part of the population. A key question for this study was whether the population had stopped recovering after the 1973 protection, and if the significant loss of sea ice had reduced survival and reproduction, and led to a decline in the number of bears. The sea ice distribution was similar in the two survey years (2004 and 2015): there was only a scattering of ice around the Svalbard archipelago, and the ice edge was further north. The estimated number of bears in Svalbard was again close to 250, indicating that the part of the population that stays in the area year-round has changed little, despite them being without access to sea ice for a much longer period each year. The number of bears in the pack ice was higher than in 2004, although not significantly so. This could indicate population growth, but the higher number could also be due to a net movement of bears westward, from the Russian sector. The proportion of females with cubs was as high as in 2004, and comparable with that observed in other healthy populations. So despite loss of good denning areas and a shrinking habitat for hunting, Svalbard's bears seem to be doing fine.

Polar bears are surveyed from a small helicopter with three observers in addition to the pilot. This photo was taken near Hornsund in southern Spitsbergen in April 2007.
Photo: Jon Aars / Norwegian Polar Institute

THE FUTURE

Our results indicate that polar bears can survive in the Barents Sea area in the future if conditions stay similar to what they are today. Polar bears can survive long periods without food, provided they have accumulated a good fat reserve during the few months in spring and summer when sea ice is present, and seals are abundant. However, the warming of the Arctic is predicted to continue, and the loss of sea ice around Svalbard is predicted be particularly profound in coming decades. We already observe that bears who mainly live in the pack ice sometimes swim up to several days and several hundred kilometres to reach land, where they can den. Swimming in cold water is more energy-demanding than walking. A further reduction of sea ice habitat could thus be detrimental to Svalbard's polar bears, whose livelihood depends on sea ice and sea-ice-associated seals. Our monitoring programme is designed to detect signs of sudden changes in reproduction and survival. ■

Diwakar Poudel, Dag Vongraven and Ellen Øseth // Norwegian Polar Institute

Management of variable environmental values in the Arctic

Designing management strategies in ice-covered arctic waters and the marginal ice zone under variable environmental conditions is a challenging task. Decision-making involving consideration of variable environmental values further increases the complexity for management. Therefore, there is a need for new methods and approaches to enable integrated management of such highly dynamic marine regions of the Arctic.

The term "value" is complex and has many dimensions. In the realm of environmental management, valuing the arctic environment is not about putting a price on nature, but more about assessing all the tangible and intangible benefits of the environment, such as ecosystem services, paying close attention to long-term perspectives and dynamic attributes. A rapidly changing climate, climatic variability and various anthropogenic factors are adding to the complexity and dynamic nature of environmental values. Ecological processes triggered by changes in the ocean environment are already causing profound changes to the ranges and ecology of e.g. benthos, arctic fish, birds, and mammals. Climate change is one of the most serious threats to arctic biodiversity. Sea ice decline strongly impacts ice-dependent species, highlighting the environmental value of ice-covered waters and the marginal ice zone. On the other hand, the retreat of sea ice will bring socioeconomic activities to previously ice-covered areas, increasing fishing, oil, gas and mineral extraction, and shipping intensity. Thus, variability of both climatic and anthropogenic factors impacts the environmental value of the Arctic. This necessitates development, adjustment and implementation of mechanisms for the management of valuable areas to safeguard biodiversity in the Arctic under changing environmental conditions, such as loss of sea ice.

In a project funded by the Research Council of Norway and the Fram Centre Flagship MIKON, we are developing options for managing environmental values despite variability and uncertainty of natural and human-induced environmental conditions. Activities include understanding the total economic values within ice-covered arctic waters and the marginal ice zone, and analysing recent approaches in management from this new perspective. The assessment of total economic value can help in the search for optimal solutions for specific policy questions and in the management decision-making process.

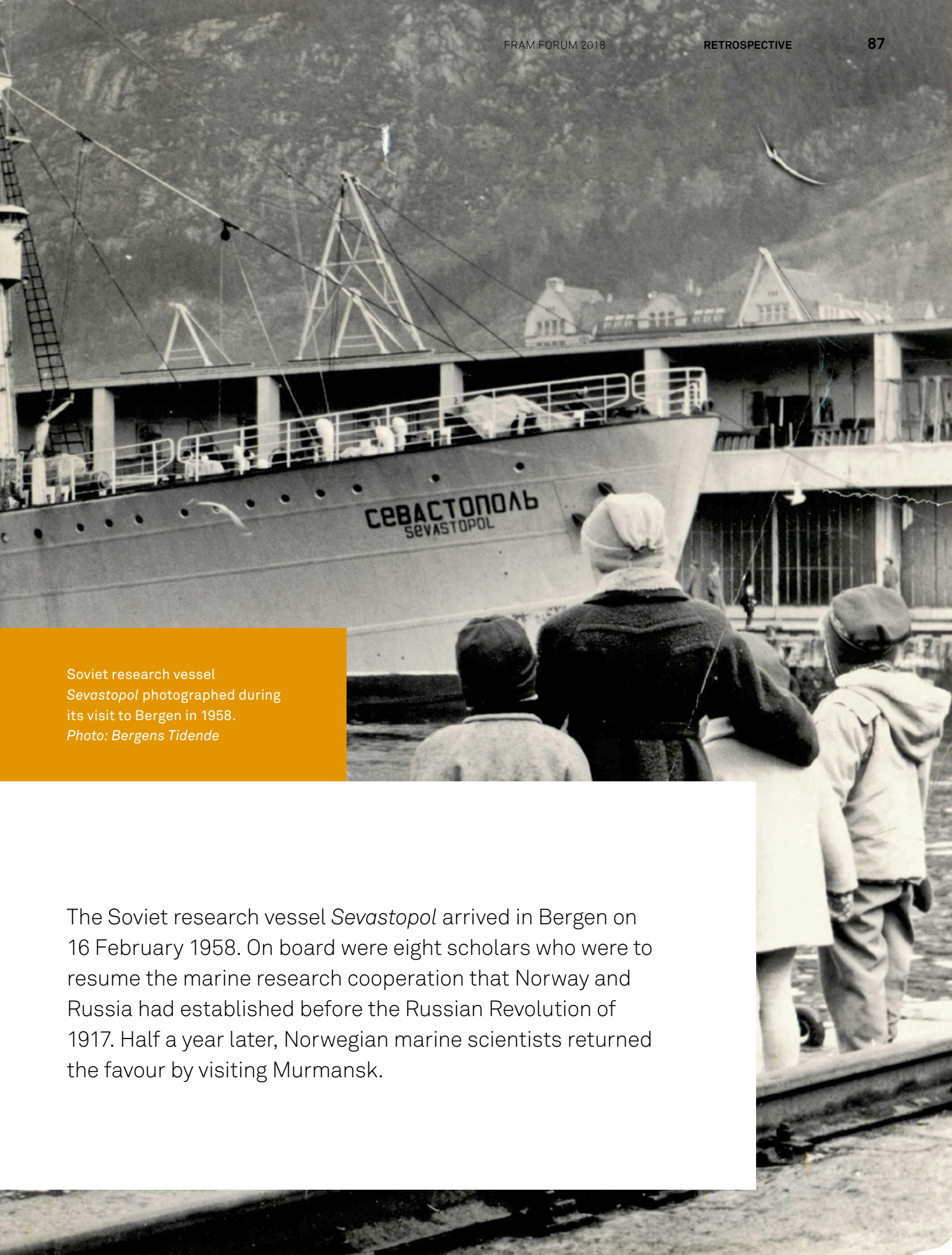
Photos: Nick Cobbing (top left), Stephen Hudson (top right), Jon Aars (bottom) / Norwegian Polar Institute

Furthermore, only a small fraction of ice-covered areas and areas including variable sea ice cover lie within marine protected areas (below 3% of the total area). In the light of suggestions to increase the marine protected areas and other marine conservation areas to reach the 2020 Aichi Biodiversity Target, this study will focus on arctic environments of high and variable value. Recent national and international management efforts will be reviewed and analysed, and management options will be recommended.

Finding new ways to manage a dynamic environment in a sound and resilient manner is hugely relevant to global society, as well as being a crucial aid to integrated ocean management. From an industrial perspective, scientifically-based management of the dynamic marine environment and its highly variable environmental values will be important for sustainable development. ■

Gunnar Sætra // Institute of Marine Research

Sixty years of Norwegian–Russian marine research cooperation



Soviet research vessel *Sevastopol* photographed during its visit to Bergen in 1958.
Photo: Bergens Tidende

The Soviet research vessel *Sevastopol* arrived in Bergen on 16 February 1958. On board were eight scholars who were to resume the marine research cooperation that Norway and Russia had established before the Russian Revolution of 1917. Half a year later, Norwegian marine scientists returned the favour by visiting Murmansk.

Norwegian marine researchers visited Murmansk in August 1958. Here they have gathered with their Soviet colleagues at the entrance to the Knipovich Polar Research Institute of Marine Fisheries and Oceanography(PINRO).
Archive photo: Institute of Marine Research

While in Bergen the researchers discussed the situation of the main fish stocks harvested by the Soviet Union (of which Russia was a part 1917-1991) and Norway. Herring and cod were the most important species for both countries, especially what we now call Norwegian spring-spawning herring and Northeast Arctic cod. The Norwegian researchers were uneasy about the Soviet vessels using a fine-mesh trawl in the Barents Sea, thus also catching a lot of small cod. The Soviet scientists expressed their concerns about Norwegian vessels harvesting far too much small herring in the fjords, most of which was used for production of fish meal and fish oil.

In the book *The Barents Sea* (edited by Tore Jakobsen and Vladimir K. Ozhigin and published in 2012) we read that this meeting of marine researchers in Bergen "signalled a break in the wall of silence that separated Soviet and Norwegian scientists who were studying the stocks of jointly exploited fish species and was an important point of departure for future cooperation" (p. 23). In 2018, Norwegian and Russian marine researchers will commemorate the cooperation that began 60 years ago.

The meeting in Bergen was also part of the International Geophysical Year, but the foundation for the cooperation was laid almost three years earlier. Before the communist revolution in Russia in 1917, Norwegian and Russian marine scientists had been in rather close collaboration both within the International Council for the Exploration of the Sea (ICES) and through direct contacts. For example, Norwegian marine research pioneers such as Johan Hjort and Fridtjof

Norwegian and Russian researchers meet frequently to discuss scientific topics. Shown here outside the entrance to PINRO in Murmansk, March 2017.
Photo: Gunnar Sætra / Institute of Marine Research

Nansen had close contact with Nikolay Knipovich, the man who built the world's first fisheries research vessel.

STARTED WITH A SUMMIT

The Soviet Union had not collaborated with ICES since the revolution of 1917, but in 1955, ICES resurrected the membership that Tsarist Russia had before the First World War. During a visit to Moscow in November 1955, Norway's prime minister Einar Gerhardsen discussed several issues with the leader of the Soviet Union, Nikita Khrushchev. Gerhardsen was of the opinion that Norway and the Soviet Union would be able to cooperate on research. According to Stian Bones, professor of history at UiT The Arctic University of Norway, this was "the start of the Norwegian-Soviet fishing cooperation that developed positively during the Cold War".

In the mid-1950s, marine researchers were not issuing recommendations about maximum quotas for fish stock, either at a national level or through ICES. Moreover, fishing in the Barents Sea and the Norwegian Sea was still a free-for-all. This eventually led to reduced catches, and the data being collected by researchers indicated that the decline in fish populations was due to over-exploitation, not natural fluctuations. Thus, there was a need for more knowledge about fish species and the ocean in general.

The fisheries research programme started soon after. A Soviet delegation visited Norway in March of 1956. It was led by the Soviet Minister of Fisheries, Alexandr

Ishkov, who had with him a number of specialists, among them several marine researchers. A Norwegian delegation led by Norway's Minister of Fisheries, Nils Lysø, visited the Soviet Union in May the same year. Over a 16-day period, they participated in political meetings, visited fish processing plants, joined a trawler on the Barents Sea, and got a close look at the Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO) in Murmansk.

Lysø wrote a detailed report after the trip, where he stated:

> "Russian exploration of the sea thus has far greater breadth than ours where the northern seas are concerned, and our fishery interests in those waters are just as great as those of the Russians. [...] I want to use (marine researcher) Finn Devold's words here: 'we have everything to gain and nothing to lose from such cooperation.'"

SAME METHODS – DIFFERENT OPINIONS

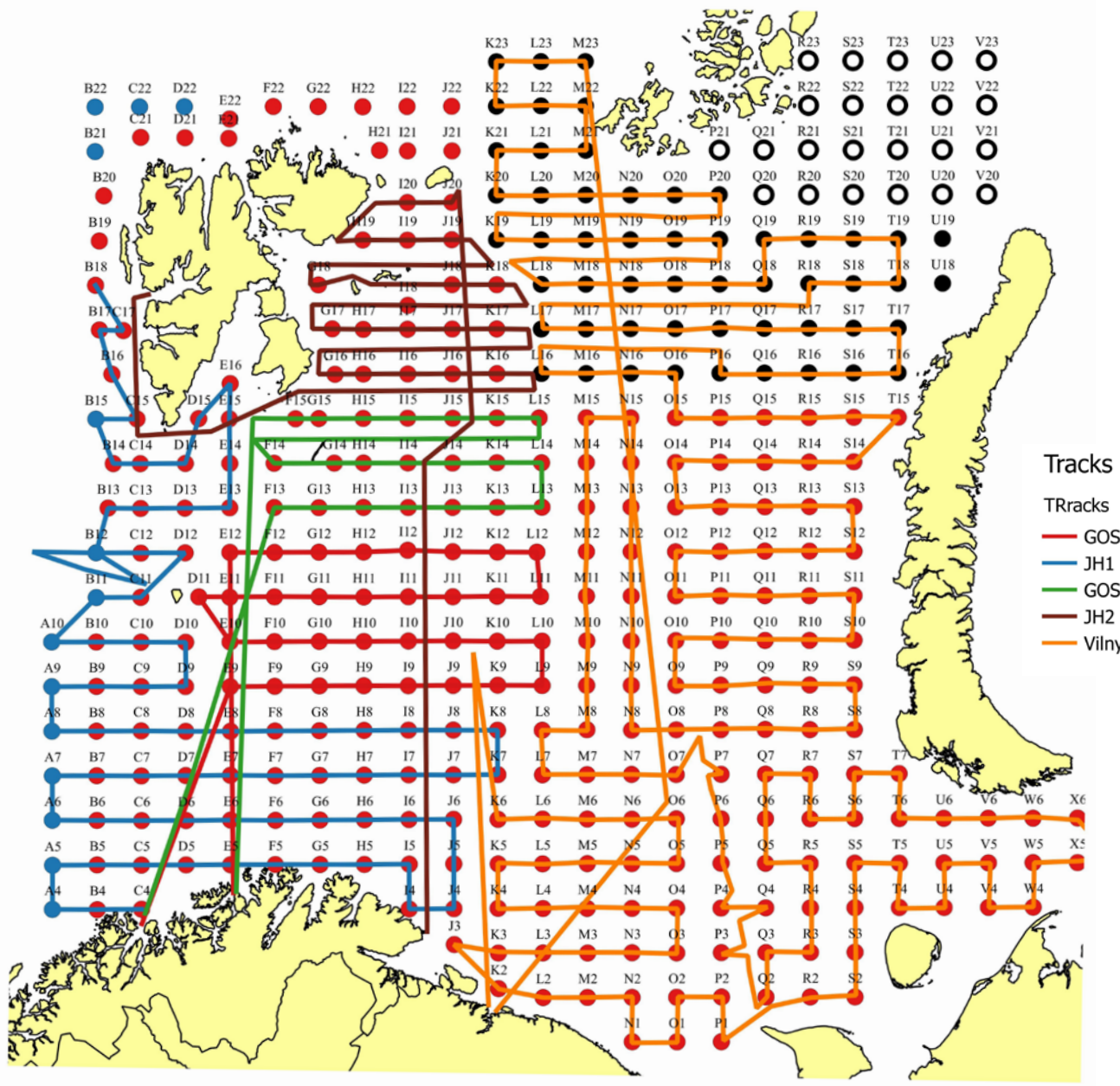
Lysø and Devold discovered that there were few practical obstacles to a potential collaboration between Norwegian and Soviet marine researchers. Their report states: "For scientific research on fish biology and hydrographic surveys, Soviet and Norwegian scientists use essentially the same methods." However, Lysø also wrote that both Ishkov and the marine researchers from the Soviet Union were critical to the extensive harvest of small herring in Norwegian fjords. They doubted that the herring stock could survive the heavy exploitation of young herring. "Advisor Devold from the Directorate of Fisheries countered this assumption with statistics from tagging studies etc. provided by Norwegian scientists," wrote Lysø. He went on to state that the Soviet scientists were not convinced, and figured that the Norwegian scientists would eventually "come to the same conclusion as Soviet scientists have reached". Herring had been on the agenda at the first meeting of Norwegian and Soviet marine researchers in Bergen in 1958, and was discussed repeatedly in the years that followed. The stock of Norwegian spring-spawning herring collapsed around 1970, at which time a 10-year moratorium on fishing this species was introduced.

In the 1950s, Norwegian scientists were worried about extensive Soviet trawling of juvenile cod in the eastern part of the Barents Sea. Nothing in Lysø's report suggests that he discussed this with Ishkov during his visit to the Soviet Union.

FROM FRY SURVEYS TO ECOSYSTEM CRUISES

Norwegian and Soviet researchers met several times in 1958 and the years that followed. The collaboration took a leap forward in 1965, when the first joint Norwegian-Soviet fry survey was carried out in the Barents Sea. The aim was to study recruitment of several fish species, as such information could help predict future developments for various fish stocks. Subsequently, several more joint research surveys were conducted in the Barents Sea to survey shrimp, capelin, cod, young herring, whales, seals, Greenland halibut and king crab. Since 2004, these surveys have been merged into a joint ecosystem survey of the entire Barents Sea.

The annual Norwegian-Russian ecosystem survey in the Barents Sea is a comprehensive expedition to expand our knowledge. The research vessels cover the Barents Sea "from A to Z" to gather data on all plant and animal life - from phytoplankton to whales. The physical properties of the ocean are examined as well (water temperatures, salinity etc.). The participants record data about waste and count birds; they take samples for analysis of contamination, radioactivity and chemical substances that do not belong in the Barents Sea. As a rule, three Norwegian research vessels cover the Norwegian seas, while a Russian ship covers the Russian sector of the Barents Sea. The participants on a fully-manned expedition include researchers, research technicians, and the crew needed to operate the vessel. Tools range from scoops and bottom trawls to collect samples from the seabed, to fine-mesh nets for sampling plankton in the water column. The researchers also use pelagic trawls to collect fish and other large organisms that live in the water, such as large jellyfish. There are observers on board that count whales and birds and determine their species.



The annual Norwegian–Russian ecosystem survey in the Barents Sea starts in the middle of August and lasts until late September/early October. The map shows the routes the vessels took, and the points mark where samples were taken.
Illustration: Institute of Marine Research/PINRO

A multitude of samples are taken during the annual Norwegian–Russian ecosystem surveys in the Barents Sea. This photo shows a capelin catch. *Photo: Andrey Voronkov / Institute of Marine Research*

PROVIDE RECOMMENDATIONS ON QUOTAS

The data collected by the researchers are analysed both to get an overview of the state of the ecosystem in the Barents Sea, and as a foundation for estimating stock populations of commercially harvested fish species. Among other things, the Norwegian-Russian ecosystem survey has revealed that several fish species in the Barents Sea have moved northeast in the last 10-15 years.

The Barents Sea is shared between Norway and Russia, and both countries want their authorities to set rules for sustainable harvesting. The species that provide the largest revenues wander between the Norwegian and the Russian economic zone. Therefore, the annual quotas for capelin, haddock, Northeast Arctic cod and Greenland halibut are determined by the Joint Norwegian-Russian Fisheries Commission. The commission, which has been setting these quotas

Odd Nakken, former head of the Institute of Marine Research, says that when Norwegian and Soviet researchers met, they sometimes talked about their families or leisure activities, but mostly they talked science. *Photo: Gunnar Sætra / Institute of Marine Research*

Vyacheslav Zilanov acted as Deputy Minister of Fisheries for several years. According to him, Alexandr Ishkov, Soviet Minister of Fisheries, convinced the top leaders of the Soviet Union that the Norwegian–Soviet research collaboration surpassed its political implications, and was important for the fishing industry. *Photo: Gunnar Sætra / Institute of Marine Research*

since Norway and the Soviet Union established economic zones of 200 nautical miles in 1977, needs reliable data on which to base its decisions. The scientists are the ones who provide those data.

POLITICAL FUNCTIONS, NON-POLITICAL WORK

In 2008, political scientists Bente Aasjord and Geir Hønneland analysed the cooperation between Norwegian and Russian marine researchers. One of their conclusions was that "the scientific basis for managing shared stocks in the Barents Sea is a basic premise for, and a driving force within the Norwegian/Russian fisheries relationship. Therefore, the marine research cooperation is not only a scientific collaboration, but also a foreign policy arena."

Nevertheless, politics has not been a part of the research collaboration, according to Odd Nakken, former director of the Institute of Marine Research. He participated in joint expeditions and research meetings during the Cold War.

> "We only discussed professional issues, or we told each other what we did in our free time, or talked about our families," he said.

Another veteran, Vyacheslav Zilanov, said the same was true for the Soviets. Zilanov was present at the first Norwegian-Soviet research meeting in Murmansk, in 1958. Later, he acted as Deputy Minister of Fisheries in the Soviet Union, under Alexandr Ishkov.

Speaking of his former boss, Zilanov said:

> "Ishkov managed to convince both the Soviet premier (Alexey Kosygin) and the foreign minister (Andrey Gromyko) that this research collaboration in some ways transcended politics, and that it was important for the Soviet fishing industry." ■

The white-tailed eagle is majestic bird and a symbol of pristine environment on the Norwegian Coast. *Photo: Trond Johnsen*

Jan Ove Bustnes and Bård-Jørgen Bårdsen // Norwegian Institute for Nature Research
Kjetil Sagerup // Akvaplan-niva
Geir Wing Gabrielsen // Norwegian Polar Institute

Multiple stressors: why even low pollution threatens top predator birds

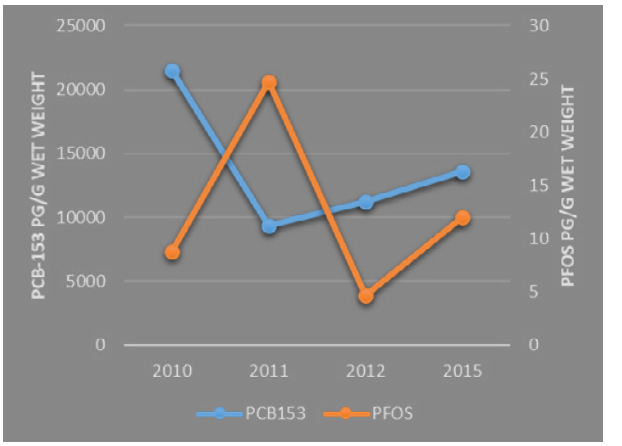
After the discovery that pesticides and industrial chemicals can spread to every corner of the world and harm wildlife, many were banned. For some, environmental levels fell quickly. But effects depend not just on levels, but also on interactions with other stressors. We need to understand these links.

Ever since humans discovered fire, pollution of the environment has been an inevitable consequence of human activity. But it was only in the last century that the widespread damage caused by pollution became a serious concern. The unrestrained emissions of persistent pesticides and industrial chemicals after the Second World War led to a ban on compounds such as DDT and PCB in the 1970s and 1980s. The environmental concentrations fell drastically in the following decades, and are currently only a fraction of those observed during the peak years.

When levels of environmental contaminants were at their highest, top predator birds suffered a great deal, commonly dying from poisoning. In fact, some raptors, notably the peregrine falcon, were brought to the brink of extinction in several regions. Fortunately, the bans mitigated such impacts, and most raptor species have recovered. However, the outcomes "death by poisoning" and "no negative impact at all" lie at opposite ends of a long scale, and the effects of environmental contaminants may not decline at the same pace as their concentrations. Our question is: To what extent are persistent environmental contaminants still detrimental to wildlife, particularly in the Arctic?

Firstly, we need to acknowledge that animals in the wild are exposed to stress such as food shortage, bad weather, predators, disease and competition. These natural stressors can weaken the animals, making them more vulnerable to manmade stressors such as contaminants. We intend to find out whether a changing environment might enhance the effects of contaminants in top predator seabirds and raptors.

Glaucous gulls. *Photo: Jan Ove Bustnes*



The glaucous gull is confined to the High Arctic but is nonetheless the north Atlantic seabird in which the most serious effects of environmental contaminants have been shown, especially at Bjørnøya. Although the environmental levels of compounds such as PCB have declined in recent years, levels still vary greatly from year to year, as shown in this figure for PCB and the fluoride-based PFOS.

Pollution has effects at every organisational stratum, from cells to populations to ecosystems. Effects on individuals and populations, such as increased death rate and suppressed reproduction - ecological effects - have been our main research focus in recent years.

The Hazardous Substances Flagship has been central in funding research on top predator birds such as arctic seabirds and birds of prey, notably the white-tailed eagle in northern Norway. In addition to legacy compounds such as DDT, PCB and mercury, emerging contaminants such as fluoride-based compounds are now being studied.

Untangling how environmental contaminants affect wildlife species is complicated, and a variety of approaches are necessary. Experimental manipulation of contaminant levels is rarely a feasible option for wildlife scientists. Such experiments often call for impractical/impossible study designs. Intentionally exposing wildlife to lethal substances is unethical or even illegal.

Instead we have adopted different strategies for unravelling interactions between contaminants and natural stressors. The well-known relationships between concentrations and the effects of pollutants prompted studies of factors causing variation in concentrations, as well as the direct effects.

Using statistical models, we have shown that much of the variation in concentrations of persistent organic pollutants in northern seabirds and raptors can be explained by factors such as temperature, precipitation and snow cover. This indicates that a changing climate may modulate the downward trends of environmental contaminants, and that naturally occurring processes may increase contaminant concentrations and thus effects.

The second approach is direct study of effects. In Kongsfjorden (Svalbard), working with our French research partners led by Dr. Olivier Chastel (CNRS), we studied how pollution affects kittiwakes. We found that pollutants influence various physiological functions in this species, for example hormones and chromosome stability. Similar results have been obtained in our studies of the common eider and the glaucous gull. Hence, we have strong indications that sub-lethal levels of contaminants are indeed affecting

The effect of environmental contaminants on the white-tailed eagle in Troms has been studied over the last decade. Elisabeth Hansen is currently doing her master's thesis on whether the immune system of eaglets is influenced by such pollutants. *Photo: Trond Johnsen*

arctic seabirds. However, before we can conclude that a given substance has serious ecological impacts, it is necessary to show relationships between that substance and reproduction or survival of the birds. Such relationships have indeed been demonstrated in glaucous gulls and kittiwakes.

We also use an experimental approach to examine multiple stressors. Our strategy is to *relieve* stress rather than to expose birds to toxins. For example, we have given medicine to top predator seabirds (glaucous gulls) to remove parasites, and found that this simultaneously removed negative effects of contaminants. We gave additional food to great skuas, and this eliminated the negative effects of contaminants on chick growth. Hence, natural stress such as parasites and food shortage seem to be working in combination with contaminants, increasing their ecological effects.

Our final approach is to examine multiple stressors using mathematical models. By combining data from specific populations with data from the literature and climate scenarios, we have simulated the potential impact of persistent pollutants. Preliminary results from a model focused on the common eider show that even small effects of pollutants could have considerable impact on the bird's survival and reproductive performance, which in turn affect population growth and viability. However, this effect was only present when the birds in the model were exposed to natural levels of the other stressors assessed (climate and egg predation). Except for egg predation, none of the stressors had any population-level effects when each was simulated in isolation.

Our studies of seabirds and raptors have provided evidence that both concentrations and effects of persistent pollutants in wildlife are influenced by other physical and biological factors, such as climate, diseases and food availability. The multi-stress approach to studying wildlife revealed that even if the legacy persistent pollutants are declining, they interact with ongoing negative impacts from natural and manmade stressors and the ever-increasing number of new pollutants, and may still be a potent factor in the health of wildlife in northern ecosystems. ■

Jane Uhd Jepsen // Norwegian Institute for Nature Research
Ole Petter L. Vindstad and Rolf A. Ims // UiT The Arctic University of Norway

Small engineers with a large impact: ecosystem consequences of moth outbreaks in sub-arctic forest

Pest insect outbreaks in the subarctic birch forest of northern Norway are among the most abrupt and large-scale ecosystem disturbances attributed to recent climate change in Europe. But such outbreaks have occurred regularly as far back as historical records go. What is new and why are moth outbreaks a cause of concern?

Moth larvae have "always" inflicted sporadic damage on forests, but the outbreak ranges of the moth species are changing in response to a milder climate. Historically, moth outbreaks in northern Fennoscandia were mainly caused by the autumnal moth - a relatively cold-adapted species. The less cold-adapted winter moth was not recorded north of Tromsø until early in the 20th century. Since then both species have spread into more northern and continental areas. During massive outbreaks after 2000, the winter moth reached outbreak densities over most of the region, far inland and all the way to the low arctic tree line in eastern Finnmark. A third species, the scarce umber moth, has expanded its range northwards in Troms during the last decades, and is now an important pest in coastal forests. Because the different moth species tend to reach their population peaks with a time lag of a few years, more species means longer outbreaks. This is bad news for the birch forest.

Larvae of three species of moth are doing all the damage. From left to right: the winter moth, the autumnal moth, and the scarce umber moth. The scarce umber moth has so far not been found in Finnmark, but is expanding its range in Troms. This year a citizen science campaign (Målerjakt, www.malerjakt.no) was launched by the Fram Centre to map the northern distribution range of this species.
Photo: Jon Aars / Norwegian Polar Institute

CRITICAL THRESHOLDS

Forests are dynamic systems able to withstand a certain amount of disturbance such as drought, storms, insect outbreaks or wildfires. After a disturbance, forests recover to their previous state. This ability of an ecosystem to maintain its structure and function despite disturbances is referred to as *resilience*. However, if disturbances become more severe or more frequent, the ecosystem may no longer be able to recover; the system has reached a *critical threshold*. In such cases even small, gradual changes in disturbance level may result in disproportionally large and sudden impacts on the forest ecosystem. In the northern birch forest, we have found several indications that such thresholds exist. First, the forest can tolerate defoliation up to a certain level, but exceeding this threshold results in rapid mass-mortality of birch. Second, there is threshold also in the potential for forest regrowth, as recruitment of both saplings and basal sprouts is poor if the mature tree layer is too severely damaged.

CASCADING EFFECTS ON THE FOREST ECOSYSTEM

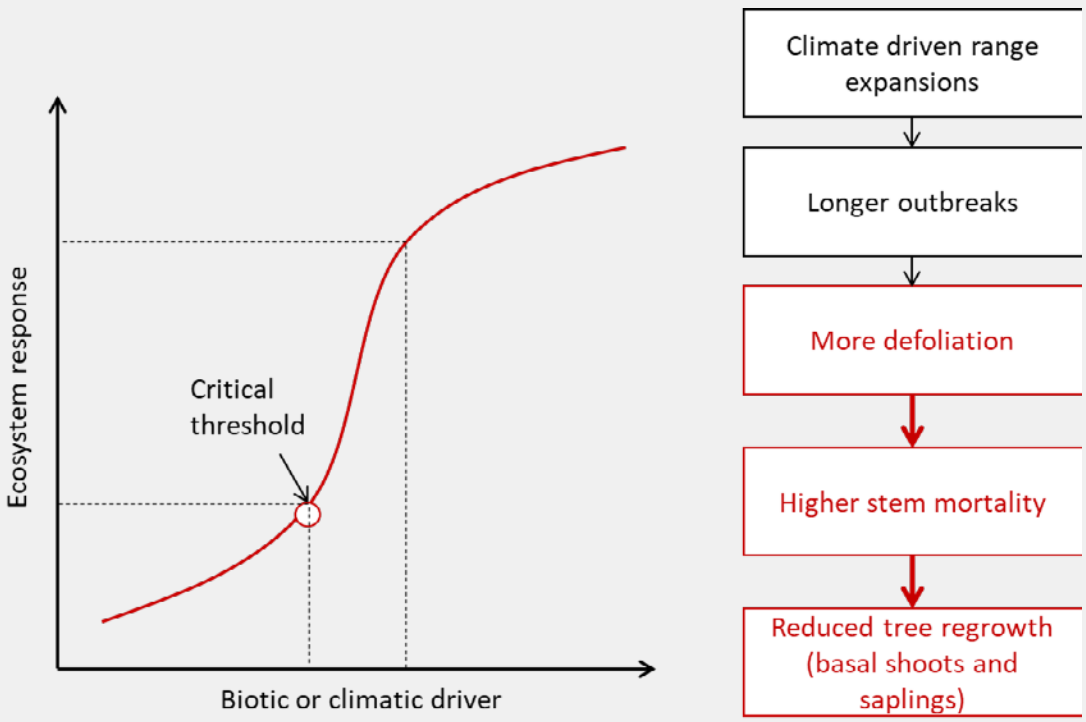
The moth outbreaks during the 2000s resulted in high forest mortality in Finnmark and northern Finland. Ten years after the outbreak, tree mortality is locally above 90%. Despite this, a new outbreak is currently in progress, which is likely to further increase forest mortality. Such large-scale diebacks are expected to have implications for many forest-dwelling species. In recent years, we have studied the short-term cascading impacts of moth outbreaks on vegetation, wildlife, and biodiversity of birds and insects. In severely affected areas, the ground vegetation underwent a complete transformation from a dominance by dwarf shrubs to grass. This was beneficial for grazing rodents, but large browsers such as reindeer avoided the more severely affected areas. The transformation was also confirmed by snow tracking in spring, when fewer tracks of the herbivores ptarmigan, hare and moose were observed in damaged forest areas. In contrast, forest-dwelling birds appeared resistant towards forest mortality, at least in the short term. This could be related to the structure of the forest remaining largely intact, and may change over time as the dead stems decompose, break and fall down. Deadwood-associated beetles play a key role as decomposers of dead stems in forests further south. In the northern birch forest, we found that their response to the vast amounts of deadwood resulting from the moth outbreaks was limited and dominated by a few species. This suggests that these beetles play a minor role as decomposers of the deadwood left by the outbreaks.

GLOOMY FUTURE FOR NORTHERN BIRCH FORESTS?

The intensified outbreaks and the presence of critical thresholds in the response of the forest raise concern for the future of the affected areas. Relatively small changes in defoliation pressure caused by continued moth range expansions under climate warming, can cause very large increases in forest mortality and subsequent recruitment failure. This will drive a transition from forest towards more open or treeless states.

Birch forest states near Polmak in eastern Finnmark. Top: A healthy birch forest. Middle: Dead birch forest following several years of severe moth outbreaks. Bottom: In the foreground the remains of a birch forest killed by a moth outbreak in the 1960s. Only the decomposing stumps are left and there is no regeneration of the forest. The birch forest on the slopes in the background was defoliated by an outbreak in the mid 2000s. *Photos: Jakob Iglhaut / Norwegian Institute for Nature Research*

However, the behaviour of ecosystems that exhibit non-linear responses, as observed here, is notoriously difficult to predict. Therefore, focused long-term monitoring of both moth outbreaks and forest responses are needed to understand the implications of insect pest disturbances on the northern birch forest ecosystem. Such monitoring is currently being developed as part of COAT – Climate-ecological Observatory for Arctic Tundra (www.coat.no). ■



Critical ecosystem thresholds. Non-linear relationships between the level of disturbance by a biotic or climatic driver (for instance duration of insect outbreaks), and the response of the ecosystem (for instance tree mortality) indicates the presence of a critical threshold. Beyond the threshold a small increase in disturbance will result in a large change in the ecosystem. For the birch forest, such non-linear relationships have been identified both between defoliation (the amount of leaves consumed by insect larvae) and stem mortality, and between stem mortality and regeneration from basal shoots and saplings (red sections of the figure).

Left: An experimental birch stump two years after logging, showing extensive production of basal shoots. The red pole is 50 cm tall. Right: Postdoc Ole Petter Laksforsmo Vindstad measuring the height of a basal shoot on a damaged birch in Polmak, eastern Finnmark. *Photos: Moritz Klinghardt / Norwegian Institute for Nature Research*

THE PROJECT:

What comes after the new pest: Ecosystem transitions following insect pest outbreaks induced by climate change in the European high North. Funded by the Research Council of Norway (project 244454), the Fram Centre Terrestrial Flagship, and participating institutions.

CAN DAMAGED BIRCH FOREST BE SALVAGED?

"Salvage logging" of birch stands damaged by outbreaks has been proposed as a means of aiding forest recovery. Logging is expected to stimulate the production and growth of basal shoots from the root system of dead or damaged birches. In 2011 we initiated a field trial in collaboration with the County Governor of Finnmark, and the Finnmark Estate Agency, to document these effects in different forest types. Within two years after logging, the number of basal shoots in experimental logging plots was on average four times higher than in untreated control plots. Shoot growth was also improved in logging plots in one of the two experimental regions. In the other region, however, heavy ungulate browsing retarded shoot growth to the extent that shoots completely failed to grow into new stems. Thus, logging can be a useful aid to local forest recovery in areas where ungulates are scarce, but is probably not worthwhile where ungulates are abundant.

Dmitry V. Divine // Norwegian Polar Institute and UiT The Arctic University of Norway
Johannes P. Werner // Bjerknes Centre for Climate Research and University of Bergen

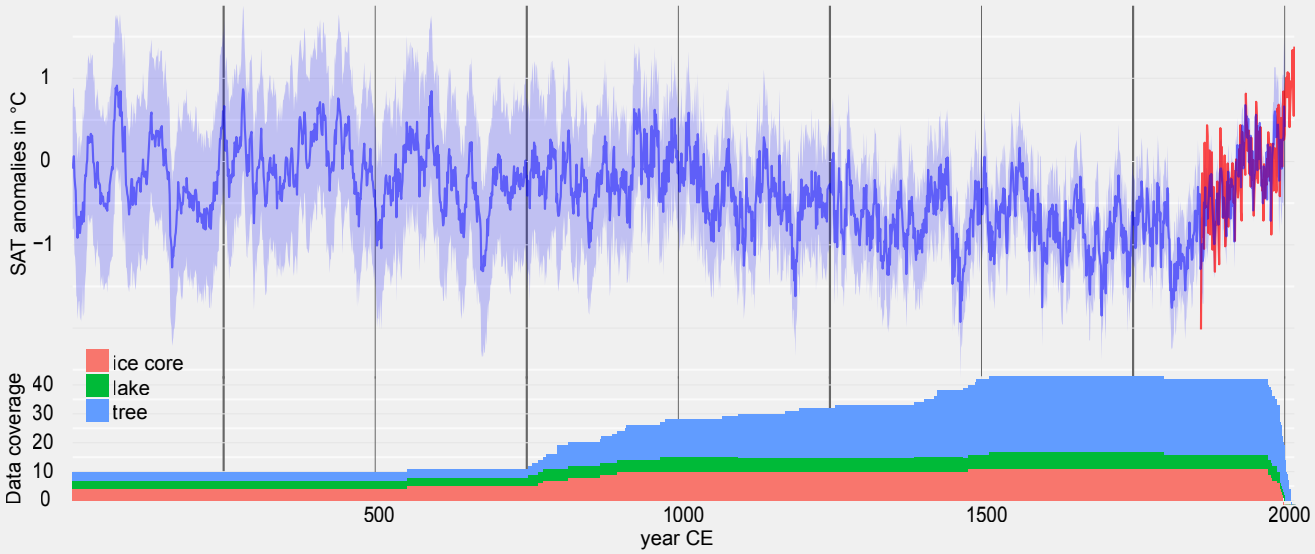
Reconstructing past arctic climate: proxy data and new methods in synergy

Knowledge of past climate variability in the Arctic is vital for improving predictions of future climate behaviour in the Arctic and globally. Using carefully selected climate proxies and a novel statistical technique in synergy, we can see the past 2000 years' arctic climate in unprecedented detail.

THERMOMETER DATA RECORDS show that the Arctic has warmed more dramatically than other parts of the world in recent decades. To look farther back in time, we must rely on indirect sources of information: paleoclimate proxy data from trees, ice, and sediment in lakes. These, in combination with dedicated mathematical and statistical methods, can help put the ongoing warming in a long-term context, telling us to what extent the modern arctic warming falls outside the range of past natural variability on decadal to millennial timescales.

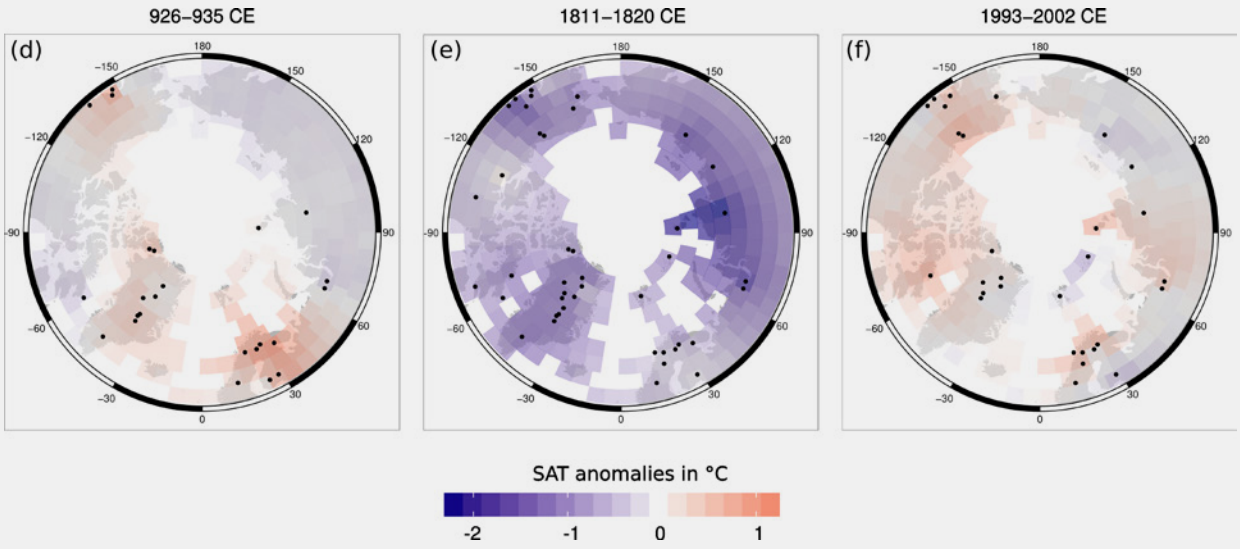
In the PAGES (Past Global Changes) initiative, an international team of scientists from Norway, Sweden and Canada has focused on reconstructing the climate history of the Arctic over the last 2000 years. Although this was not the first attempt to reconstruct arctic climate for that time interval, two innovative aspects make this study a major step forward:

1) use of 50 carefully selected temperature-sensitive proxy data series from the arctic region, mainly from the PAGES2K global climate proxy database
2) development and application of "BARCAST" a mathematical and statistical method for reconstructing climate parameters in specific areas and time intervals.



Top part of graph: Reconstruction of variability of summer surface air temperature (SAT) over land north of 60°N. Blue line: reconstruction ensemble mean, blue shading: range of possible SAT, red line: instrumental data.

Bottom part of graph: Number of proxies used in the reconstruction over time.



Spatial anomalies of surface air temperature relative to the calibration period (1850-1980) for the two warmest decades of the reconstruction: 926-935 during the MCA and 1993-2002, the most recent 10 years of the reconstruction. To highlight the contrast between the cold and warm episodes of climate history of the Arctic over the last 2000 years, the coldest decade of the reconstruction (1811-1820) is also shown. Black dots show location of proxy series used in generating the temperature field reconstruction. From MCA to LIA, temperatures cooled by 2.0±0.5°C and from LIA to the latest decade (1993-2002) they warmed by 1.9±0.5°C.

NOT ONE CLIMATE RECONSTRUCTION, BUT MANY

BARCAST has enabled an explicit treatment of proxy data from natural archives with chronological uncertainties for the first time. It has also generated more than 600 possible independent scenarios of temperature north of 60°N, enabling further analyses of natural climate fluctuations in the arctic region. In particular, we could now focus on the regional expression of past major climate anomalies, such as the Medieval Climate Anomaly (MCA) that occurred in the Arctic between about 920 and 1060, followed by continuous cooling into the Little Ice Age (LIA). The LIA did not end until after 1840, when the current warming trend started. Development of this new reconstruction enabled us to compare temperatures in the Arctic during past warm and cold extremes, with anomalies observed in modern times.

One of the major questions we have tried to answer was whether temperatures in the Arctic during the Medieval Climate Anomaly were warmer than those we see today.

Statistical testing of the new reconstruction did not show conclusively that the contemporary mean summer temperatures exceed peak temperatures during the MCA on centennial or decadal time scales. However, the spatial coherence of warming over the last decades of the reconstruction (1980s onwards) seems unprecedented at least back to year 750.

One should also note that the reconstruction ends already in 2002, yet we know that the Arctic has been warming continuously over the last 15 years. With these years included in the analysis, we believe the signature of the contemporary warm period would be even more prominent. ■

FURTHER READING:

Werner JP, Divine DV, Charpentier Ljungqvist F, Nilsen T, Francus P. (2017) Spatio-temporal variability of Arctic summer temperatures over the past two millennia: an overview of the last major climate anomalies. Climate of the Past, https://doi.org/10.5194/cp-2017-29

INNOVATIVE TOOLS

The PAGES 2K Consortium: A global multiproxy database for temperature reconstructions of the Common Era.
Available at doi:10.1038/sdata.2017.88

The BARCAST+AMS model (Bayesian Algorithm for Reconstructing Climate Anomalies in Space and Time, including Age Model Selection).
Available at doi.org/10.5194/cp-11-533-2015

Daniel Hitchcock, Tom Andersen and Katrine Borgå // University of Oslo
Øystein Varpe // University Centre in Svalbard

Pollutants and energy brought from afar in arctic geese

Barnacle geese migrate annually from the UK to Svalbard to breed. The birds need energy both to fly to Svalbard and to produce eggs, and they carry some of that energy with them in the form of fat. But fat also tends to accumulate pollutants. Can stored pollutants teach us anything about the geese?

Daniel Hitchcock working with the goose colony on Storholmen in Kongsfjorden. The island is approximately 1 km^2 and houses almost 300 breeding pairs every summer. *Photo: Margje de Jong*

Our project followed the geese on their journey north, investigating their potential energy and pollutant sources. We want to know if feeding at different sites and timing of energy acquisition and allocation also affect how pollutants are taken up and transferred from mothers to eggs.

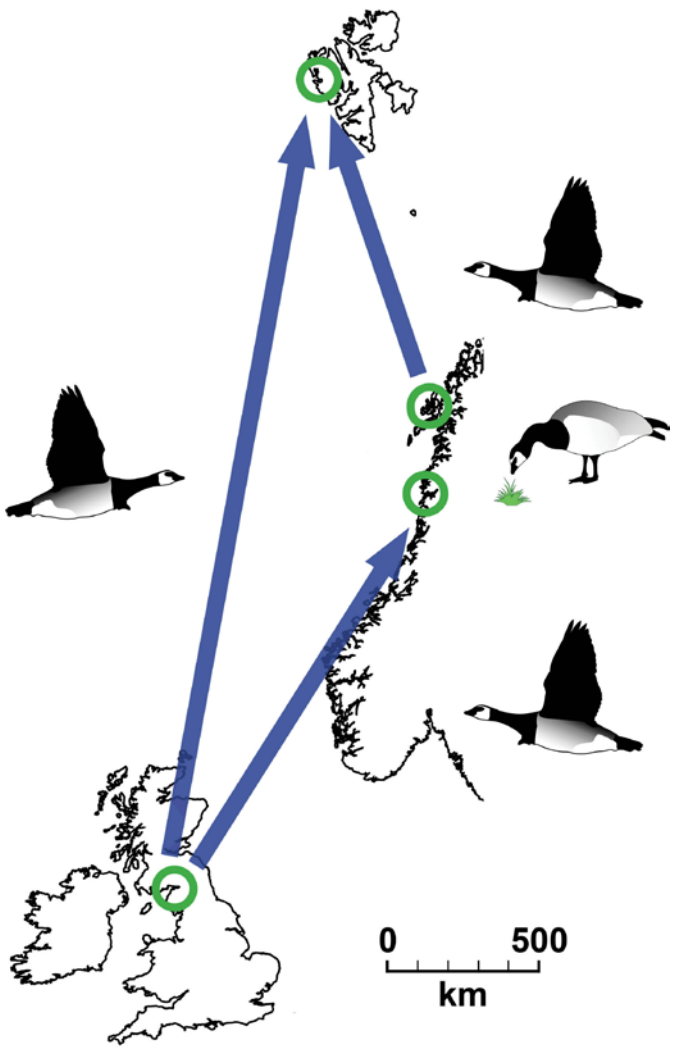
TRAVELLING TO BREED

Over 2 500 km of land and ocean separates the summer and winter grounds for barnacle geese. In winter, the birds spend most of their time at Solway Firth wetlands on the west coast of Great Britain. During late spring, they fly northwards along the Norwegian coast and across the southern Barents Sea to Svalbard. Many of the geese make a pit stop along the Helgeland coast and Vesterålen in northern Norway.

Goose migration varies in terms of when the birds leave their overwintering grounds, which route they take, and how long they spend at the different feeding sites. The timing and route of migration can tell us when and where energy is acquired to produce eggs. From an ecotoxicological perspective, this makes the geese an exciting study species, since we can use pollutants as chemical tracers to track migration and energy source.

A MIGRATION OF RESEARCH

From May to June in 2016, we joined the geese on their journey towards the Arctic. A small team of scientists flew from the Netherlands and southern Norway to Svalbard to study some of the goose populations living on island colonies accessible only by boat.



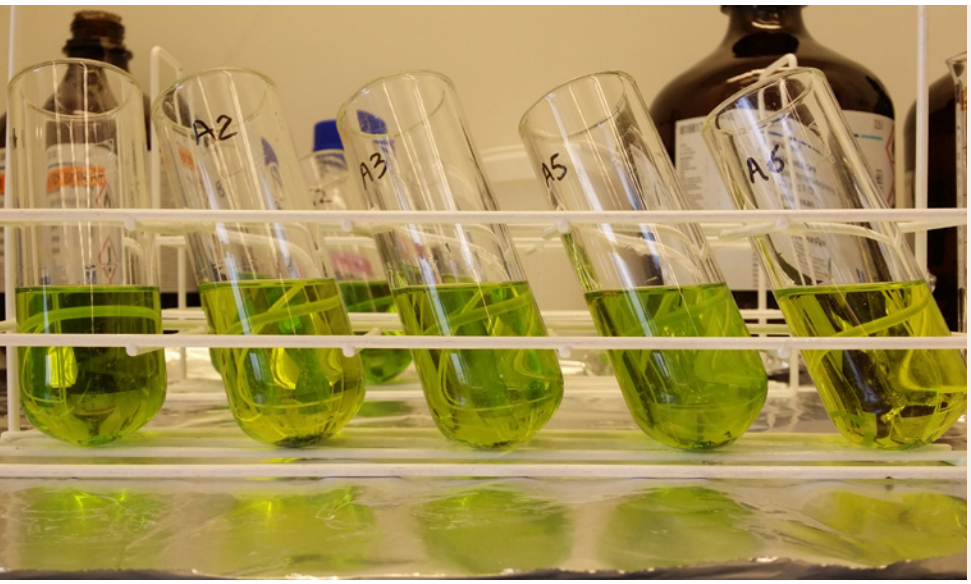
The barnacle goose's annual journey from Great Britain to Svalbard. Geese migrate north to breed, either flying directly or with stopovers along the Norwegian coast. Green circles indicate main feeding sites.

Barnacle geese nest in pairs. These two are marked with easy-to-read rings and breed on Storholmen in Kongsfjorden. Approximately one third of the ringed Svalbard population was sighted in northern Norway in 2016. *Photo: Daniel Hitchcock*

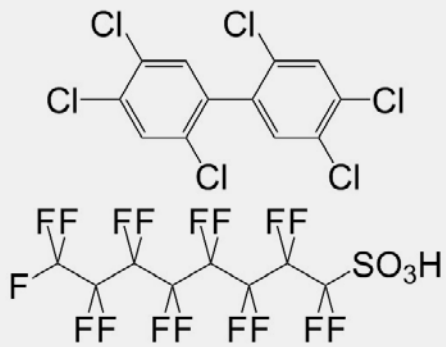
We had hoped to arrive at the Svalbard breeding grounds before the geese did, but were beaten to the chase. It was an exceptionally early year for the geese, with most females laying eggs already on the first of June, about a week earlier than a decade ago.

The researchers competed with the geese for grass samples along the flyway. Birdwatchers equipped with telescopes and notebooks recorded sightings of ringed birds during their stopover in northern Norway. And at the Svalbard breeding grounds, scientists ventured forth onto the breeding island, recorded biological details of the colony, and sampled eggs from the nests.

We brought egg and grass samples back to Tromsø where NILU - Norwegian Institute for Air Research analysed for pollutants, including fat-soluble substances (such as PCB and HCB) and protein-associated chemicals (PFASs and Hg). In grass and eggs we also measured the composition of stable isotopes of carbon and nitrogen to determine where along the flyway geese acquired their energy to produce their eggs. Combining this with our biological data we get a picture of where the geese were travelling, when they were arriving in Svalbard, and if the area where they were acquiring energy to produce the eggs was also reflected by the pollutants we were detecting.



Preparing vegetation samples for pollutant analyses at NILU in Tromsø. *Photo: Daniel Hitchcock*



The chemical structures of PCB-153 and PFOS, two persistent organic pollutants detected in most of the eggs.

PROJECT INFORMATION

The full title of this project is: Effect of migration strategy on pollutants in eggs of Arctic breeding barnacle geese (*Branta leucopsis*).

Partners: Daniel Hitchcock, Tom Andersen and Katrine Borgå – University of Oslo; Øystein Varpe – UNIS; Maarten Loonen – University of Groningen; Nicholas Warner and Dorte Herzke – NILU; Ingunn Tombre – NINA; Paul Shimmings – BirdLife Norway; Larry Griffin – Wildfowl & Wetlands Trust

Financial support: Arctic Field Grant (RiS ID 10386), Svalbard Environmental Protection Fund (16/84), Fram Centre Flagship: Hazardous substances (WP2.3_2017), University of Oslo (PhD Scholarship)

Maarten Loonen (left) takes biological measurements of adult geese while Daniel Hitchcock (right) records the data. Maarten has worked with this goose population for over two decades. *Photo: Margje de Jong*

Sampling vegetation in Svalbard requires much patience – and a permit! Arctic grass is extremely scarce, particularly where researchers must compete with grazing geese. *Photo: Katrine Borgå*

WHICH POLLUTANTS?

The chemicals we investigated include persistent organic pollutants (POPs), which contains an organochlorine structure and take decades to break down in the environment. POPs are regulated globally under the Stockholm Convention, and mercury (Hg) under the Minamata Convention. Many scientists are interested in how animals are exposed to such pollutants, and what effects they might cause. These chemicals serve as model pollutants in ecotoxicology - we understand much about their chemical properties and association with fats and protein in biological material.

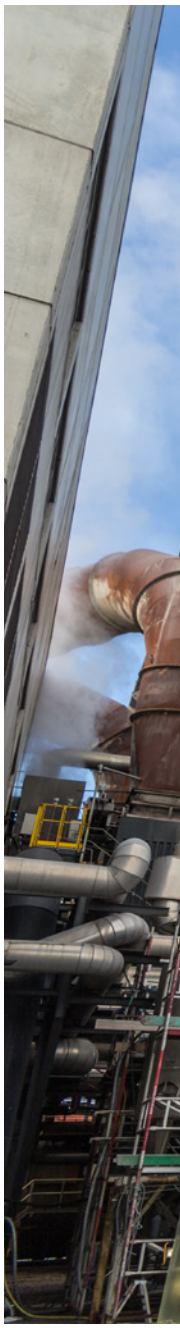
Fortunately for the goose eggs, the levels of these pollutants were quite low. We often report pollutant concentrations on a nanogram per gram basis (ng/g), which is the same as parts per billion. Imagine if everyone on earth wore blue t-shirts, except seven who wore red t-shirts - those seven would be roughly equivalent to 1 ng/g. And that's the amount of pollutants we detected in the eggs.

POLLUTANTS AS CARRY-ON BAGGAGE

The stable isotope results suggest that geese acquire a large proportion of their resources towards egg production from southern regions, including the United Kingdom and Norway. However, we cannot rule out additional feeding sites along the coast of Svalbard, closer to the breeding grounds. Even though pollutant concentrations in eggs are low, our preliminary results allow us to track the migration of pollutants within geese from southern areas up to their breeding grounds in Svalbard. ■

Mathilde Torsøe and Tonje Engevik Eriksen // UiT The Arctic University of Norway

Exploring the potential of microalgae



Our planet is getting warmer. Humanity might be losing the battle against climate change. But solutions can be found in unexpected places.

We are about 60 kilometres southwest of Tromsø at Finnfjord AS, one of Europe's largest producers of ferrosilicon and silica. Huge machines tower above our heads, releasing 300 000 tonnes of carbon dioxide into the air every year. That's a problem. Not far from the machines are huge tanks of murky brownish water. Bubbles rise to the surface. That may be part of a solution.

"This tank contains 14 000 litres of seawater and is home to about 500-600 billion diatoms," says Gunilla Eriksen, chief engineer at the Norwegian College of Fishery Science at UiT. "The algae strains being cultivated here were collected in Svalbard and the surrounding fjords." She describes how smoke from the factory is pumped into the tanks.

> "The smoke contains 6-7% CO_2 and NOx gases - not a welcome addition to the atmosphere. Mixing algae and contaminated gas may not sound like a good idea at first. But algae cannot live and grow without CO_2 and nitrogen."

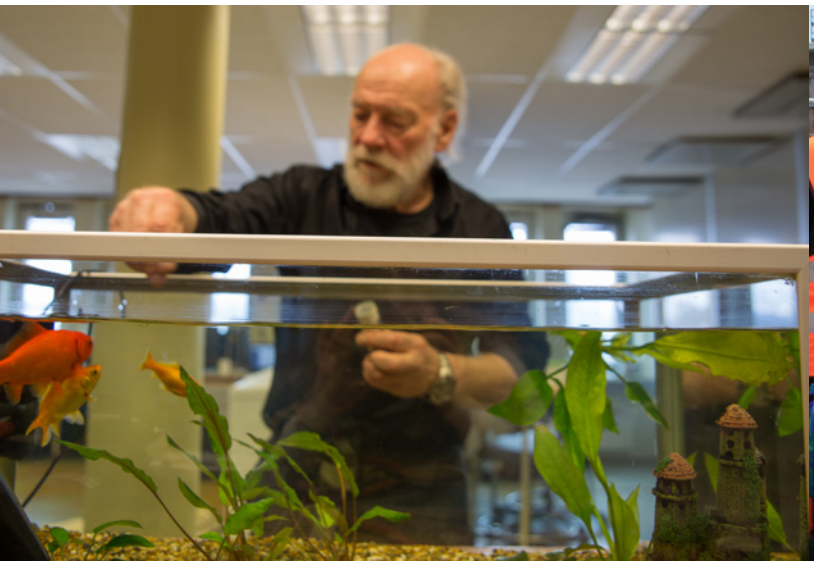
A WILD IDEA

The idea of installing algae tanks at the smelting plant has been in gestation since the 1980s, largely thanks to UiT professor Hans Christian Eilertsen, who has dedicated much of his career to developing this concept. For 42 years, Eilertsen has been studying and cultivating diatoms, some of the world's smallest organisms.

These microalgae may help Norway meet its obligations under the Paris Climate Agreement, which aims to limit global temperature increase to 2°C above pre-industrial times by cutting greenhouse gas emissions.

"Diatoms take up CO_2 naturally through photosynthesis. Algae in the oceans are responsible for more than half of the carbon dioxide uptake on Earth. They are great at absorbing light and converting it to organic biomass, and they do it at high rates," Eilertsen explains. For years he has wanted to mass cultivate algae, hoping to take advantage of their many qualities.

Every year, Finnfjord AS produces approximately 100 000 tonnes of ferrosilicon, an alloy of iron which is used in stainless steel and carbon steel. The plant in Finnfjord runs almost exclusively on electricity, consuming nearly as much as the entire city of Tromsø. The algae tanks at the bottom left of this photo are dwarfed by the industrial buildings. *Photo: Tommy Hansen*



Hans Christian Eilertsen feeding the goldfish who live in the laboratory at Finnfjord AS. They appear to do quite well on the salmon feed produced by the algae in the experimental photobioreactors. *Photo: Tommy Hansen*

Norwegian Prime Minister Erna Solberg paid visits to UiT in Tromsø and Finnfjord AS 18 May 2017. Here she is conversing with Anne Husebekk, Rector of the University. *Photo: Tonje Engevik Eriksen*

Geir Henning Wintervoll, general manager of Finnfjord AS, shows UiT Rector Anne Husebekk and Prime Minister Erna Solberg around the factory. *Photo: Tonje Engevik Eriksen*

Mass cultivation requires large amounts of CO_2 gas - which can cost as much as 12 000 NOK per tonne. That is why the Faculty of Biosciences, Fisheries and Economics at UiT entered into an unusual partnership with Finnfjord AS. The company was sceptical at first, but eventually agreed.

> "The notion that algae could clean industrial emissions sounded too good to be true. It was a pretty wild idea," says CEO Geir Henning Wintervoll with a smile.

Diatoms use photosynthesis to convert carbon dioxide and inorganic nutrients into high-energy organic matter: algae biomass. To do this, they need light as an energy source. The UiT researchers usually cultivate algae in tank reactors, which take up much less space than standard photobioreactors. When the first reactor was set up at the smelting plant in 2015 and the researchers prepared to lead exhaust fumes through the water, they didn't know what would happen. Would the algae tolerate these gases at all?

DRAMATIC EXPANSION

In 2008, Finnfjord decided to become the world's first carbon-neutral ferrosilicon plant. They installed Norway's largest thermal energy plant to convert excess heat into electricity. This allows the smelting plant to recover more than 30% of the energy used in production. The temperature of the seawater that passes through the plant and the composition of the gasses the plant emits are favourable for algae cultivation.

The researchers inject flue gas into the algae tanks to produce algae biomass. The gasses dissipate in the water and are absorbed by the algae, which grow by cell division. The algae biomass is then separated from the cultivation fluids in a centrifuge. Algae have proven to be very good at absorbing these exhaust fumes, and the biomass qualifies as "clean" according to standards set by the Norwegian Food Safety Authority. But it has been a bumpy road.

> "The reason we got much better results is that our method of cultivation runs counter to all the other cultivation initiatives. Our challenges have always been related to scaling up the biological and technological processes and making production profitable," says Eilertsen.

ALGAE AND DIATOMS

- Algae is a generic term for a variety of aquatic plants, from single-celled species to seaweed many metres in length.
- Algae make up most of the earth's biomass. All life in the sea is based on primary production by autotrophic microalgae.
- Diatoms are a class of microscopic, single-celled algae. They are among the world's smallest organisms. The class includes about 200 000 species.
- Diatoms have lived on the earth for over 150 million years and are considered fossils.
- Diatoms can be found in fresh water and salt water, in humid environments on land and in the polar regions.
- Diatoms are one of the main components of phytoplankton in Norwegian seas and in other oceans.
- Diatoms are the cause of the algae blooms that occur every spring in Norwegian coastal waters.
- Researchers at Finnfjord only work with one type of diatom, which has been carefully selected and tested over time. The algae have been growing at the Tromsø campus for several years.

UiT professor Hans Christian Eilertsen, showing Prime Minister Erna Solberg one of the algae cultivation tanks. *Photo: Tonje Engevik Eriksen*

But the project had several other positive surprises in store.

> "It turns out that algae biomass that has been grown with exhaust fumes actually has lower levels of organic pollutants and heavy metals than biomass produced by simply infusing air. We also see higher lipid content in algae exposed to exhaust - especially the omega-3-fatty acids. The bigger the tank, the more the algae thrive. This is probably because the environment more closely resembles their natural ocean habitat."

Eilertsen speculates that living conditions become more homogeneous and stable as tank size increases.

Encouraged by these successes, the researchers have moved forward with the next phase of the project, which involved a dramatic expansion. Three tanks of 26 000 litres each were recently replaced by one tank of 300 000 litres, and the laboratory facilities were upgraded.

Grants from the Troms County Council and Norway's National Budget made the upgrades possible.

Diatom biomass has many potential uses. Initially, the researchers at UiT wanted to explore ways to use the omega-3-rich algae for things like biofuels and health foods.

> "We have been engaged in bioprospecting for years, in collaboration with MarBio, trying to find molecules in the algae that could be used for example to cure cancer or diabetes. But we eventually realised we should focus our efforts on producing fish fodder," says Eilertsen.

"THE NEW OIL" NEEDS BETTER FOOD

Salmon farms in Norway currently use fodder made mainly from soybean and other terrestrial plants. The salmon is a predator and needs omega-3 in its diet; despite this fact, salmon fodder contains little omega-3. This has led to a gradual decrease in omega-3 levels in Norwegian farmed salmon in recent years. Some politicians are calling salmon "the new oil" for Norway, but Eilertsen believes fish fodder with adequate amounts of omega-3 is a prerequisite for success.

"From a sustainability perspective, it's much better to feed the salmon with fodder produced in a way that also removes hazardous emissions than giving them fodder grown on farmland," says Eilertsen. "Farmland should really be used to grow food for people."

When Norway's Prime Minister Erna Solberg visited Finnfjord in May of 2017, Eilertsen showed her the world's first salmon fodder made entirely of diatoms.

"We've been testing the product on our goldfish. They look pretty fit!" laughs Eilertsen, as we peer into the goldfish aquarium at the Finnfjord laboratory.

The new grants will also make it possible to continue developing plans for a national carbon capture and utilisation centre here at Finnfjord, in collaboration with UiT.

PLANS FOR THE FUTURE

If the positive results keep coming in, the researchers' next goal will be to construct enormous algae tanks holding at least 4-5 million litres of seawater. They hope to establish a fish farming zone at the smelting plant to minimise the distance between the fish and their fodder.

"If all the CO_2 emitted from Finnfjord is used to produce fish fodder, we might be able to cover 7-8% of Norway's total fish fodder requirements," says Eilertsen.

He points out that a fish farm near the plant would not only reduce emissions. It would also reduce transport and storage costs considerably.

"The carbon footprint would be minimal. Profitability would be more easily attainable than it is for the existing salmon farming industry," says Eilertsen, who estimates that the million-litre tanks could be in place in two or three years.

The collaboration between UiT and Finnfjord has been a success for both parties.

"Starting something like this from scratch is prohibitively expensive. Running the programme from an existing plant is a win-win situation. We would never have got the project running without Finnfjord's infrastructure and CO_2 and NOx emissions - and the generous regional funds. And without us, the company would never have embarked on a process to reduce emissions from the plant this drastically," says Eilertsen with a smile.

CEO Wintervoll agrees.

"This is a fantastic project! Things have gone extremely well, and extremely fast. One man's meat is another man's poison." ■

MAIN FINDINGS FROM THE FINNFJORD PROJECT

- Algae are robust and can survive in industrial environments.
- They tolerate industrial gas emissions quite well. When the density of the algae is great, they need more nutrients than are naturally available in the sea.
- When the algae are fed gasses generated at the plant, the lipid content increases and heavy metal content is reduced.
- Algae thrive in large tanks. The UiT researchers speculate that the larger the tank, the more closely it replicates conditions in the algae's natural ocean environment.

Åshild Ø. Pedersen // Norwegian Polar Institute
Larissa T. Beumer // Aarhus University
Brage B. Hansen // Norwegian University of Science and Technology

Sea or summit: wild reindeer foraging in changing high-Arctic winters

Wildlife may partly buffer changing environmental conditions by adjusting their behaviour. Over thousands of years in a hostile environment, the wild Svalbard reindeer has developed strategies to cope with severe winter feeding conditions. How are they responding to increasingly rainy and icy winters?

A young Svalbard reindeer feeding on washed up kelp and seaweed. *Photo: Malin Daase*

Small arctic plants encapsulated in ground ice. *Photo: Odd Arne Olderbakk*

SNOW PACK PROPERTIES such as snow depth and hardness are significant foraging barriers to northern herbivores in winter, when plant quality and quantity are at the lowest. In Svalbard, winter climate change is rapidly affecting the terrestrial tundra ecosystem, mainly due to more frequent mild spells and "rain-on-snow" (ROS) events. ROS events can leave ice layers in the snow pack or on the ground, as heavy rain may percolate through the snow and accumulate on the frozen ground. Thick solid ice then encapsulates the plants, making them inaccessible for the herbivores.

Several studies show negative effects of ROS on reindeer body mass, in turn affecting survival, reproduction and population growth rates. At the same time, other studies strongly indicate that a variety of behavioural responses to ice-locked grazing grounds - shifts in diet or use of space - may partly counteract negative fitness consequences on the individual level. With increased spatial isolation due to reduction in sea ice and fast ice in the fjords, the opportunities to escape poor foraging conditions through range displacement and seasonal migration are currently reduced. Thus, the extent to which individuals and populations of Svalbard reindeer are able to adapt to effects of winter climate warming will depend heavily on their ability to adjust behaviour.

MOVING OUT

Studies using VHF and GPS collars on Svalbard reindeer have demonstrated partial seasonal migration, particularly under difficult winter foraging conditions. The earlier view that Svalbard reindeer are confined to small, year-round individual home ranges has been nuanced after GPS-collars were mounted on female reindeer in Central Spitsbergen (since 2009) and along the west coast (since 2014). A study in Nordenskiöld Land showed that individual reindeer shifted their

Feeding craters on the beach. *Photo: Åshild Ønvik Pedersen*

range, mainly in icy winters, from valleys with a lot of ground ice to valleys with less ice. Compared with individuals that stayed behind in the icy valley, the reindeer that moved had lower over-winter loss of body mass, lower mortality rate, and higher subsequent fecundity. On the west coast, when fjord ice was still present in the early 2000s, up to 35% of female reindeer left their home range on Brøgger Peninsula for better winter foraging conditions at Sarsøyra, crossing the fjord ice in Engelskbukta. Recently, however, fjord ice has been absent in the area, and data from GPS-collared reindeer since 2014 suggest that such migration no longer occurs.

FORAGING AT THE SEASHORE

Increased monitoring, longer time series and improved technology such as GPS collars and stable isotope analysis of diets, have provided new evidence that coastal reindeer use marine food resources to buffer effects of widespread tundra icing. During the population monitoring in the extreme icing winter of 2010, when thick ground ice covered 98% of the lowlands, 13% of the reindeer in the coastal populations south of Ny-Ålesund fed on washed-up kelp and seaweed in late winter. Young animals appeared to be overrepresented among the individuals that applied this foraging strategy, which probably represents a last attempt to avoid starvation under particularly severe foraging conditions. Our recent analyses based on annual winter population monitoring between 2006 and 2016, along with GPS-collar data and stable isotope analysis of reindeer faeces and their different food sources, now confirm the link between this marine foraging strategy and rainy and icy winter conditions.

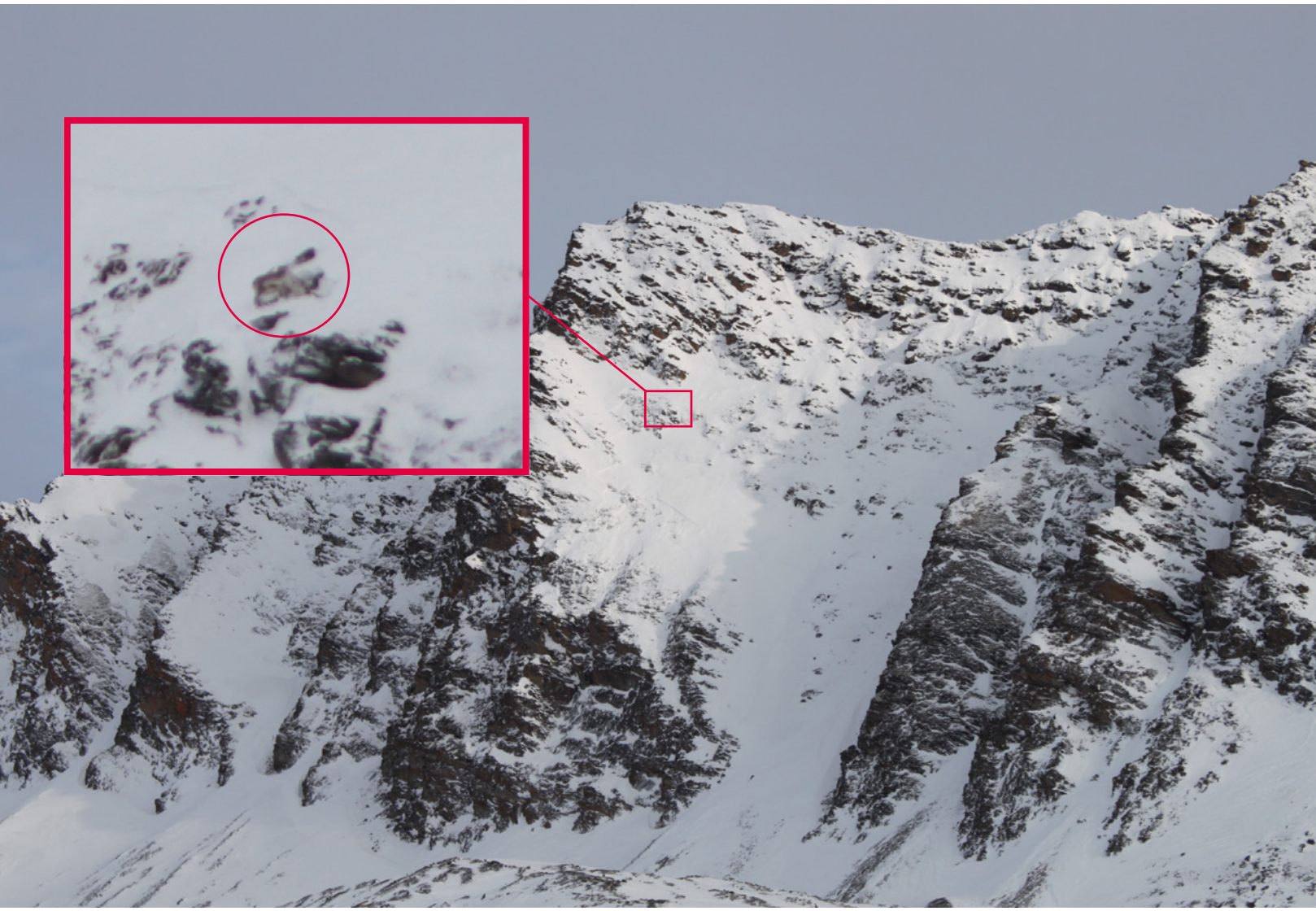
Capture-mark-recapture studies are important for understanding reindeer responses to climate change. Currently, COAT encompasses such studies in both Nordenskiöld Land and along the west coast of Svalbard. *Photo: Erik Ropstad*

CLIMBING THE HILLS

Although kelp and seaweed are heavily utilised by some individuals, this food source appears to give the reindeer diarrhoea and needs to be combined with more "normal" food plants. Accordingly, the monitoring data from the coastal populations suggest that most reindeer also apply other strategies to cope with poor winter feeding conditions. Some individuals gather in small, ice-free hotspots in the lowlands, using a fine-tuned sense of smell to locate ice-free microhabitat beneath the snowpack. The largest group observed during the annual winter count in 2012, had almost 60 individuals gathered in a small area. Another strategy, particularly common among adult males, is to move to high elevations and steep mountain slopes where ground ice is less likely. Despite extremely low plant biomass at such high elevations (i.e. polar desert), and a substantial mortality risk due to avalanches, up to 50% of the reindeer were located in steep terrain above 300 m altitude during icy or particularly snow-rich years, while few or none used this habitat in more favourable winters. Thus, in recent poor winters, many coastal reindeer tended to forage either at high elevations or along the seashore. This demonstrates a dual spatial response to worsening winter feeding conditions when lack of fjord ice restricts dispersal, with a strong selection for the periphery of the foraging niche.

MONITORING SPATIAL ECOLOGY

The reindeer module of the Climate-ecological Observatory for Arctic Tundra (COAT: www.coat.no) focuses on climate impact pathways on reindeer dynamics and spatial ecology. A substantial part of the COAT Infrastructure funding is for telemetric equipment such as GPS collars that enable researchers to track individuals' spatial responses and fitness. The targeted instrumentation on reindeer along with an extended climate observation network, in both inland and coastal populations, will enhance our understanding of the spatial responses of reindeer to changes in their habitats. Such knowledge is particularly important under global warming, because behavioural buffering may be crucial for population persistence under rapid environmental change. This is especially the case for long-lived species like reindeer, with long generation time and limited ability for rapid evolutionary adaptation to a new arctic winter landscape. ■



Svalbard reindeer foraging at high elevations in steep, alpine terrain along the west coast of Svalbard (Kaffiøyra). *Photo: Brage B. Hansen*

FURTHER READING:

Pedersen ÅØ, Stien A, Soininen E, Ims RA (2016) Climate–Ecological Observatory for Arctic Tundra – Status 2016. Fram Forum 2016: 36-43

See reindeer feeding on the seashore in "Vill Viten" (episode 4). https://tv.nrk.no/serie/naturforskerne

Starrlight Augustine and JoLynn Carroll* // Akvaplan-niva

AmP: An online database to support environmental management decisions

Biodiversity plays a key role in ecosystem structure and functioning and is crucial for conservation and environmental management. The problem with biodiversity is that it's so *diverse*. To understand an ecosystem, scientists must also understand countless species. That's where AmP comes in.

AmP, Add-my-Pet, is a unique web-platform providing data, models and parameters for key animal species. Scientists develop trait-based approaches to tackle management issues by investigating which traits make a particular species invasive, or determine its ability to handle pollution or climate change. AmP is a database where scientists can access the traits of interest for a variety of species. AmP is unique in that it integrates powerful models with the data. These models, based on the Dynamic Energy Budget theory, apply to all animal life on earth and cover all aspects of energetics throughout the life cycle, from the start of embryo development to death by ageing.

A POWERFUL TOOL

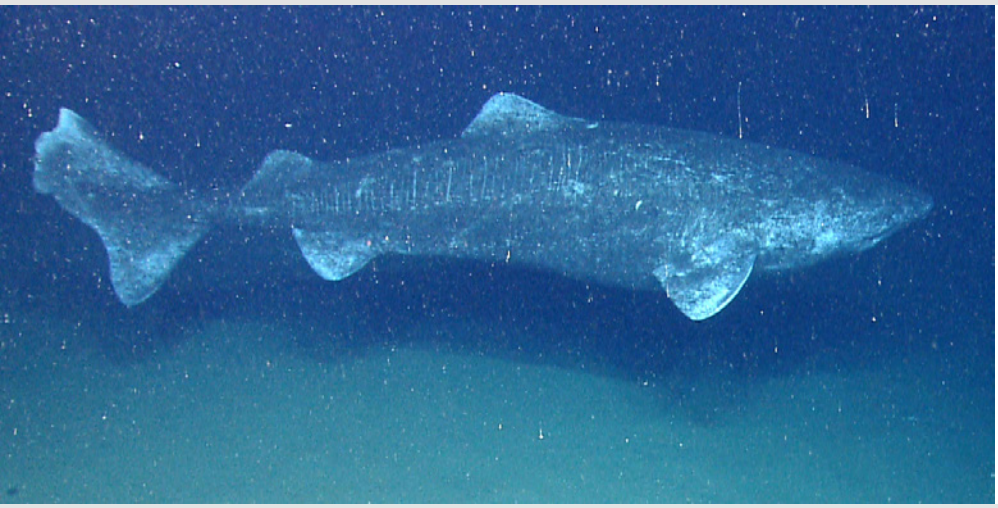
Assessing potential effects of climate change and pollution on animals requires answers to some questions. Just how big can this animal become? How much does it reproduce? Users can extract these and many other parameters for any of the animals that are represented in AmP.

AmP integrates life-history data with powerful models that allow calculations for whatever food and temperature the users need for their study. Moreover, missing data (like metabolic rates), can also be calculated. These powerful models and parameters are designed to aid understanding of species sensitivity patterns.

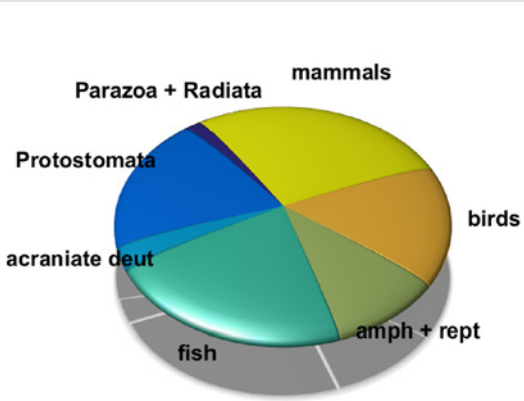
THE SPECIAL CASE OF THE GREENLAND SHARK

The Greenland shark inhabits arctic waters. In 2016, Danish scientists found that these sharks reach adulthood at 150 years and have a mean lifespan of four centuries! These findings were added to existing information in AmP, such as maximum size, size at adulthood, pup size and number of pups per litter. This allowed scientists to infer that it takes somewhere between 8 and 18 years for pups to develop in the mother's womb, and that a female Greenland shark may produce 200–700 pups in her lifetime!

* Also affiliated with UiT The Arctic University of Norway



The Greenland shark may live for four centuries, reaching adulthood after 150 years. Its maximum size is about 6.5 m, and it reaches almost 5 m at adulthood. Apart from these facts, very little is known about this mysterious creature. All its basic life-history information can be accessed via AmP. *Photo: NOAA Okeanos Explorer Program [Public domain], via Wikimedia Commons*

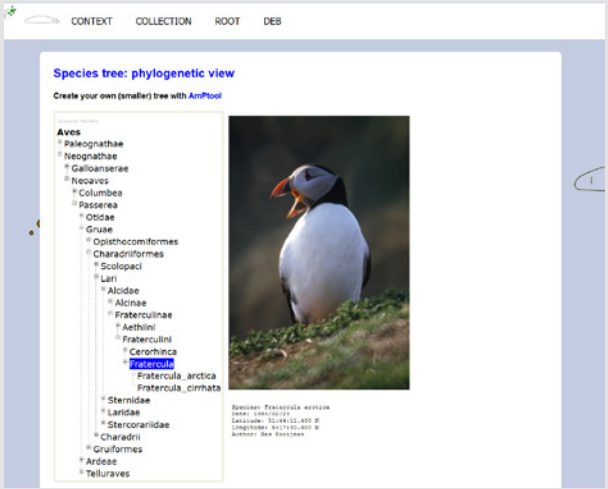


Animal groups represented in AmP. As of January 2018, the collection includes 1012 species, some of which are extinct. All major phyla are represented, spanning a body mass range of 16 orders of magnitude – from bacteria to blue whales.

UNDERSTANDING SPECIES SENSITIVITY

Loss of biodiversity is a major challenge in our era, and is partly due to habitat loss. When making decisions related to land use and resource management, one can ask what makes one species sensitive and another successful, even invasive? An invasive species isn't necessarily "an invader" from elsewhere; it can also be a resident species that takes over. Of the many new species that enter a new area and survive, very few become "invasive". Let's take the example of minks and otters: in Norway, minks are invasive, wreak havoc, and their success comes at the expense of otters. Understanding why a species can be invasive helps us predict risks to local communities when conditions change.

Ecosystems are complex communities comprising many species constantly in delicate and vital interplay. How would they react to release of a chemical into the ecosystem? Which species will be sensitive and perhaps even disappear? Understanding species sensitivity is the holy grail of ecotoxicology. A passionate community of scientists develop AmP because it is a powerful and open source tool which can support ecosystem-based decision-making. ■



"Add-my-Pet" is operated and maintained by an international board of curators with expertise in taxonomy, biology, statistics, fisheries, conservation, ecotoxicology and ecology. It represents a new multi-disciplinary trait-based approach that aims to: (i) find the simplest organisation principles for metabolism upon which all life is based and (ii) understand taxon-specific patterns as variations on this common theme. All the species in the collection can be accessed via a dynamic tree of life where users can walk along branches to the "leaves". Alternatively, species can be accessed via their English or Latin names.

Mathilde Torsøe and Karine Nigar Aarskog // UiT The Arctic University of Norway

Sunlight in a wintry world

What is likely northern Norway's biggest solar energy system was recently installed at UiT in Tromsø. Researchers believe that within a few years, most new buildings will have their own solar panels.

We are standing on the roof of the Natural Sciences building at UiT surrounded by solar panels 1.5 metres high. Despite the grey skies, several of them are turned steadfastly skyward.

"Some of the panels are mounted on sun trackers so they always face the sun," says Clara Good, postdoctoral fellow in renewable energy at UiT. "That makes them more effective." The panels have solar cells that can utilise light on both the front and the back side, which means they can make use of sunlight reflected from the snow below them as well as the rays of the midnight sun standing low in the sky. "Double-sided systems produce up to 35% more energy than single-sided systems," she adds.

This system is probably the largest in northern Norway and the only one in Troms that is connected to the existing power grid.

This array of solar panels is an important part of the Arctic Centre for Sustainable Energy (ARC), one of the newest research institutes at UiT. Several academic disciplines have joined together to explore future renewable energy solutions and find ways to manage greenhouse gasses.

Yngve Birkelund is one of the key players at the Centre and an associate professor in the field of renewable energy. "UiT has been researching renewable energy for quite some time," he says. "ARC was founded to consolidate existing projects and help spread the word about the research UiT is doing on renewable energy. ARC will focus on the big projects."

ARC was founded in 2016, with funding intended to last five years. The Centre hopes that by 2022, UiT will be at the international forefront of research and education on sustainable energy for arctic conditions.

At present, ARC's two main activities are the Finnfjord project (see article on page 112), and a project that explores hybrid systems for renewable energy, of which the solar panels are a part. The latter has been underway for several years, investigating and developing hybrid energy solutions. That means combining several renewable energy technologies to generate, store and distribute energy in a robust and secure manner. Before ARC, little research had been done in this field in Norway.

Clara Good and Yngve Birkelund present the solar panels on the roof of the Natural Sciences building at UiT. Good explains: “This is a research system. The solar panels were installed at slightly different angles so we can study energy yield in different situations. It’s also possible to change the angle on many of them.”
Photo: Mathilde Torsøe

Associate professor Bjarte Hoff works with power electronics, energy conversion, micro-grids, and low-voltage installations. *Photo: Espen Dalmo*

ARCTIC CENTRE FOR SUSTAINABLE ENERGY – ARC

Received 110 million NOK in financial support from the university in 2017. These funds will be used to finance 8 new professorships, 8 new research fellowships and 8 postdoctoral positions in renewable energy and carbon capture and storage.

The research centre is a collaboration between the Faculty of Engineering and Technology at the Narvik campus and three faculties in Tromsø: the Faculty of Natural Sciences and Technology, the Faculty of Biosciences, Fisheries and Economics, and the Faculty of Humanities, Social Sciences and Education.

ARC is comprised of several disciplines from different fields. Most employees work in the field of physics, electric power, IT or biology, but researchers in political science, philosophy and mathematics also work at ARC.

> "Most renewable sources provide energy intermittently, but by connecting multiple systems we hope for a steady flow of energy. When there's no sun, maybe there's enough wind. We think hybrid plants are the way to go in Norway's future. People whose cabins run on solar energy sometimes have to wait for the sun before using electrical appliances. Some solve that by having a small wind turbine in addition to solar panels, which is in fact a type of hybrid system," Good explains.

UiT's hybrid project started with one small windmill, one solar panel and one standard car battery.

> "We used the two energy sources to simulate local production of electricity, and the energy was either stored in the battery packs or used for basic heating. The new solar cell system will allow inquisitive students and researchers to find out how to best integrate renewable energy into modern society, particularly in arctic climates," says Yngve Birkelund.

FINANCIAL SUPPORT

One issue the researchers at ARC are exploring is whether communities or individual buildings might eventually become self-sufficient in terms of electricity. Researchers believe most future buildings in Norway will be built with solar cells on the roof, but they do not foresee every household having its own wind turbine.

> "Solar cell systems don't take much space," says Clara Good. "Today's solar panels can be integrated into the walls or roof of a building. But wind turbines need to be pretty big to be efficient, and few of us have enough space in our back yards."

She and Birkelund are encouraging builders, architects, homeowners and farmers to plan for and install solar facilities on the roof right from the start, rather than installing them later. Retrofitting actually costs much more.

> "Instead of putting slate or tiles or your roof, cover it with solar panels," quips Birkeland. "The price is about the same, and now there are several colours to choose from."

Enova - a state-owned company whose mission is to reduce greenhouse gas emissions - has been supporting the owners of city buildings with as much as 28 750 NOK to set up a solar energy system. The Municipality of Oslo was covering an additional 40% of the installation costs for city residents who put a solar cell system on their building.

But the municipality is withdrawing financial support next year because they feel their work is done. The goal was always to establish a market for such products in the city, and to push prices down. The cost of a solar panel system has fallen significantly in recent years, and the technology keeps getting better. With support from Enova, it now costs about 70 000 NOK to install a solar panel system on an average residential house in Norway.

According to Clara Good, the average household needs 30-40 m^2 of solar cells to cover 5000 kWh of consumption every year. For comparison, driving an electric vehicle requires an average of about 2 500–3 000 kWh per year.

Even though Birkelund and Good do not foresee many wind turbines in urban areas, there is a substantial market for turbines on farms, which usually have plenty of space. Many farms in Sweden and Denmark already use wind turbines, and there are a few in Norway.

The solar panel system consists of 34 panels, each 1½ metres across; together, they cover about 55 m^2 of the roof. Nineteen of them provide electricity to grid and 15 will be set up to charge batteries. *Photo: Clara Good*

GOOD CONDITIONS IN NORTHERN NORWAY

Believe it or not, researchers think that northern Norway has excellent conditions for solar energy - at least when the sun is up. The solar cells used in Norway work better at lower temperatures, and can capture energy in the sunlight reflected off snow.

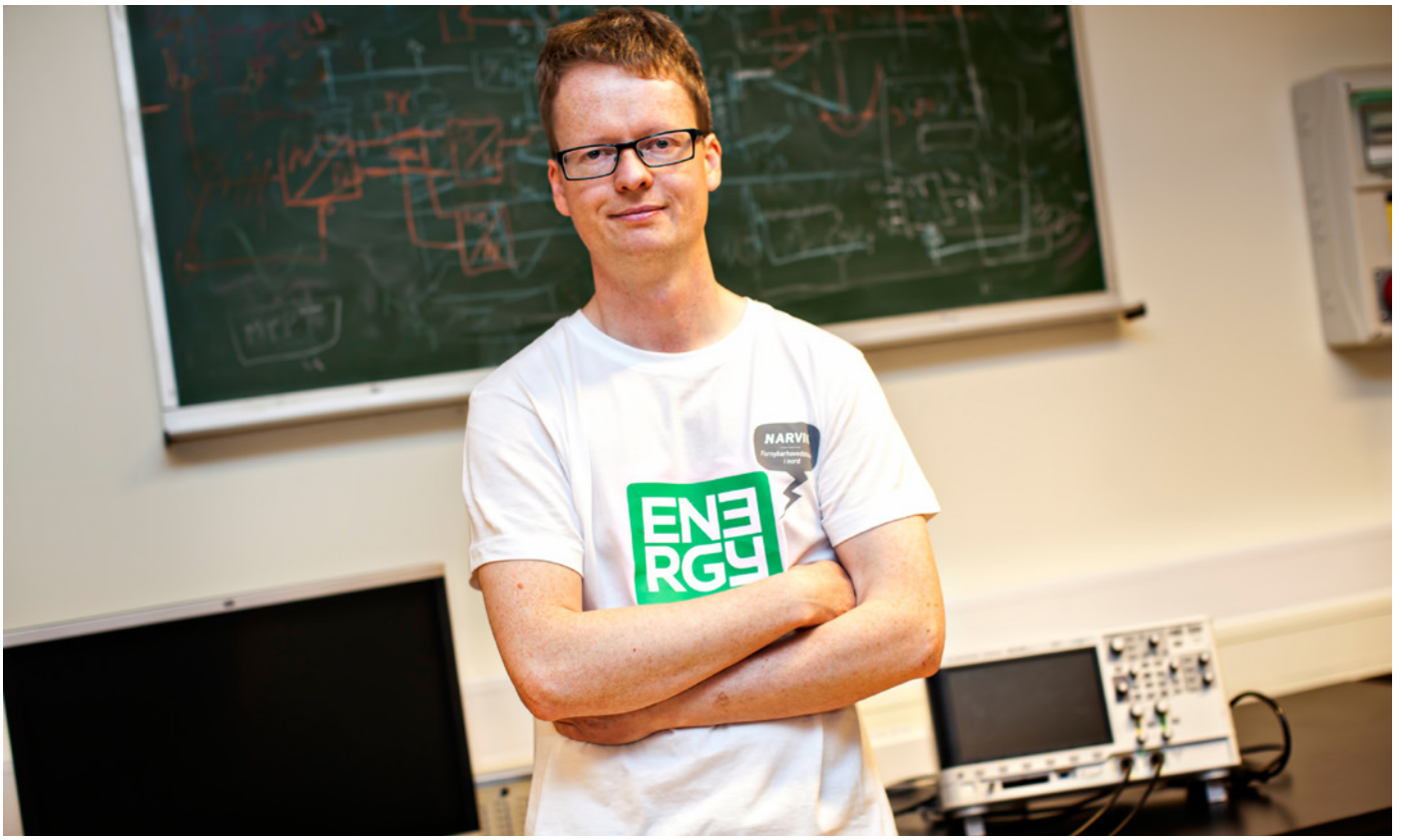
> "Conditions are actually fantastic on a sunny winter day in northern Norway," says Good. "And in the dark season we use hydroelectric power."

Good and Birkelund don't believe that people will switch to renewable energy solely for ideological reasons. "It will take both carrots and sticks," says Birkeland. "Norwegian society is trying to bring about a Green Shift through legislation, financial incentives and tax rebates, as in the case of electric cars. These efforts have already created a viable market for electric vehicles in Norway. Renewable energy for homes and buildings can be introduced in the same way."

The researchers are convinced that renewable energy is on the rise both in Norway and globally.

"Our goal at ARC is to explore new ways society can implement the green technologies we are trying to develop," says Birkelund. "The electrical grid gets overloaded when everyone comes home from work or school and starts making dinner, doing the laundry and charging the electric car - all at the same time." Clara Good is working on an ARC project to find out how solar power can be used to charge electric cars. The idea is to link various solar panel systems to charging stations via a virtual network, creating a "solar bank".

> "The solar cells will 'deposit' energy in the solar bank, then car owners 'withdraw' electricity from an 'account' to charge their car," she explains.



Bjarte Hoff believes incentives or laws may help consumers become more energy-savvy. *Photo: Espen Dalmo*

Associate professor Bjarte Hoff at UiT's Institute for Electrical Technology says that this kind of technology will be crucial in addressing climate issues in the future.

Hoff is part of a research project called Arctic Energy, which looks at how households could make use of "virtual power plants". The idea is to regulate energy consumption via control units and use the various resources at the time when their energy production is highest.

> "Virtual power plants would allow us to balance production against consumption, using resources when they are available rather than relying on a gas plant that's constantly producing energy," Hoff explains.

The technology already exists in Germany and Sweden, but before a similar system can be implemented in Norway, rules and guidelines must be adjusted to prevent misuse.

Hoff thinks the authorities should offer economic incentives for people who use energy when overall consumption is low, or introduce laws requiring that consumers be hooked up to a virtual power plant.

By January 2019, all Norwegian households will be equipped with "smart" electricity meters that can provide information on what time of day electricity is cheapest. Yngve Birkelund believes that smart meters are the key to connecting electric devices like induction heaters, water heaters and electric cars to virtual power plants. ■

Louise Kiel Jensen, Ingvild Finne, Håvard Thørring, Trine Kolstad and Øyvind Aas-Hansen // Norwegian Radiation Protection Authority
Agnes Raaness, Robin J. Watson, Vikas C. Baranwal and Jan Steinar Rønning // Geological Survey of Norway
Frøydis Meen Wærsted and Lindis Skipperud // Norwegian University of Life Sciences
Anne Katrine Normann// Norut

One uranium mountain – different trails to the summit

Orrefjell mountain, in Salangen valley, northern Norway, has one of Norway's largest uranium deposits. The area is used for recreation and as pastureland for rough grazing animals, and the catchment area to the south is settled, with farms and houses. What does it mean to live on a mountain of uranium?

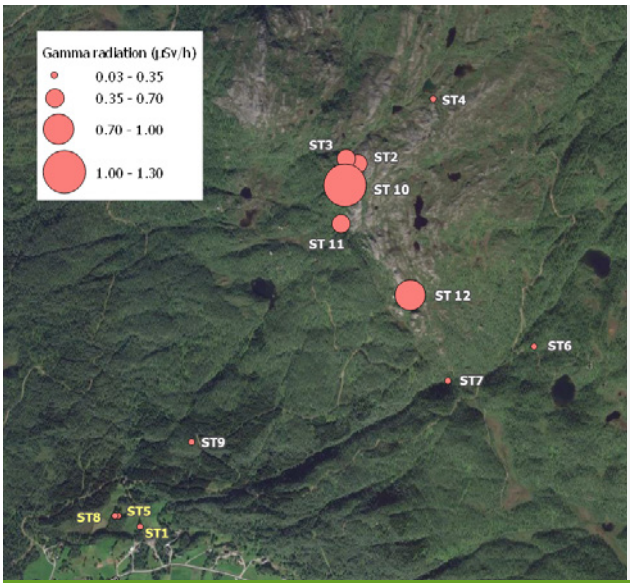
THE MAIN PURPOSE of the research project Case Orrefjell was to investigate the implications of living in and using an area with elevated levels of radiation. The project was a cooperation between natural and social scientists with a broad scope covering studies of local geology, environmental transfer of radioactive substances, human exposure to radon, and the risk perception of people living in the area. Local residents were strongly involved by measuring radon in their houses and answering a questionnaire. A class of first year students from the local high school assisted with the fieldwork, local involvement and outreach of the project.

GEOLOGY AND ENVIRONMENTAL TRANSFER TO BIOTA

The uranium deposit at Orrefjell was first discovered in the late 1950s by Henry Lund from Salangen and further documented by Geological Survey of Norway over the decades that followed. The geologists involved in Case Orrefjell provided a baseline evaluation of the geology in the area, adding to existing knowledge. The biologists and environmental chemists used this information to locate sampling sites with a gradient of background radiation. To evaluate the transfer of radionuclides from soil to plants, both were sampled at each site. The collected plant species are either important for grazing animals or produce berries picked for human consumption.

Generally, the uptake of radionuclides in biota varied with the concentration of the radionuclides in the soil, as shown by uptake of radium-226 (a daughter nuclide of uranium) in bilberry heath and berries. Interestingly, the heath accumulated higher concentrations than the berries. There are no indications that the elevated background radiation or consumption of local products poses any major risk to those who use the area.

Meeting up at the summit. *Photo: Louise Kiel Jensen*



The sampling sites in Case Orrefjell. Yellow text denotes stations sampled for soil on cultivated grassland and white text denotes stations sampled for soil and plants. The size of the circles relates to the background radiation measured at each site.

RADON

Another of the daughter nuclides of uranium is radon, a noble gas known to increase the risk of lung cancer. Norwegian authorities set a limit of radon in houses to 200 Bq/m^3 above which homeowners are advised to implement mitigating measures to lower the radon concentrations as much as possible, preferably to below 100 Bq/m^3. The physicists in the project suspected that the uranium at Orrefjell could influence the radon concentrations in nearby houses, so we asked all households in Øvre Salangen to measure residential radon during the winter 2016/17.

In some places, 20-30% of the households exceeded the recommended upper limit of 200 Bq/m^3 in Øvre Salangen. Nationally, less than 10% of houses have radon concentrations above 200 Bq/m^3, and the percentage of such houses is clearly higher in Øvre Salangen and highest close to Orrefjell itself. However, large variation in radon concentrations in neighbouring homes is common and may be due to local variation of radon in the ground, building constructions, airtightness towards the ground and habits of aeration and heating. Everyone should therefore measure the radon concentrations in their own home.

The physicists and the geologists in Case Orrefjell are also working together to develop and improve the national susceptibility map for radon. The data from Case Orrefjell will be used in this process.

RISK PERCEPTION AMONG INHABITANTS

The social scientist conducted a survey of inhabitants' awareness of risk from radiation in general and from radon exposure specifically. About 200 respondents completed the survey, of whom 71% live in Salangen. Of the respondents living in Salangen, 70% were aware of the elevated uranium levels in Orrefjell, but also replied that this did not affect their use of the area.

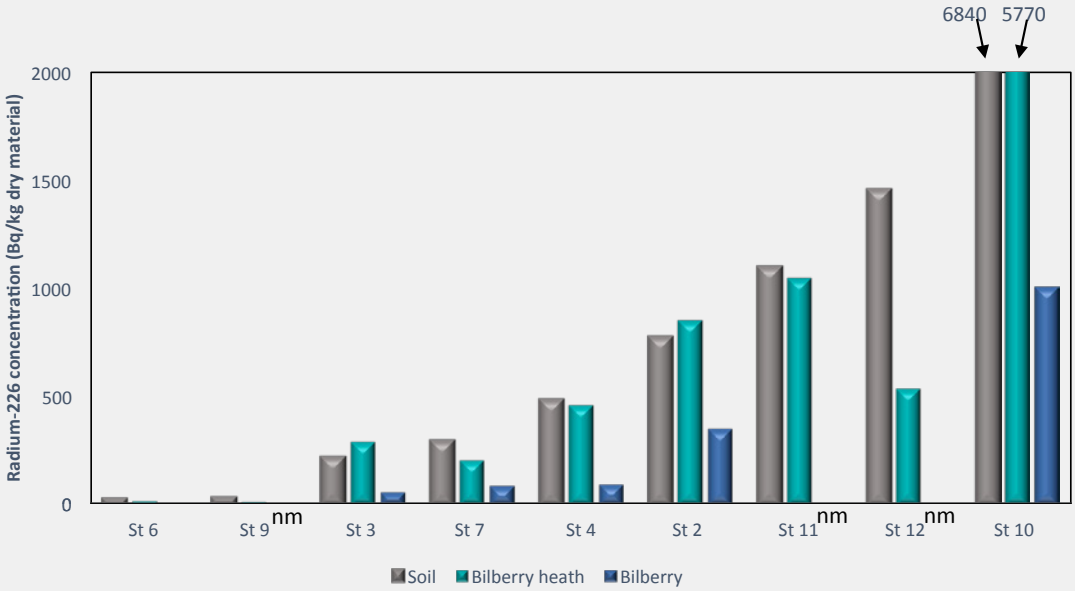
The greatest radiation risk to human health in the Orrefjell area is the exposure to indoor radon and most respondents were aware of this health risk. They also knew that the Norwegian authorities recommend all households to measure radon levels, but only one in five had acted accordingly and performed measurements. Some had found elevated radon levels in their houses, but very few had taken steps to mitigate the danger. This aligns with their apparent complacency about being exposed to radon, and their lack of perceived risk in their living and working environments.

Only 10% could recall having received information about radon from the local authorities and 80% of respondents welcomed more - and more easily accessible - information on local radon. We therefore provided the municipality with basic information about radon for distribution.

DIFFERENT TRAILS TO THE SUMMIT – COMMON VIEW

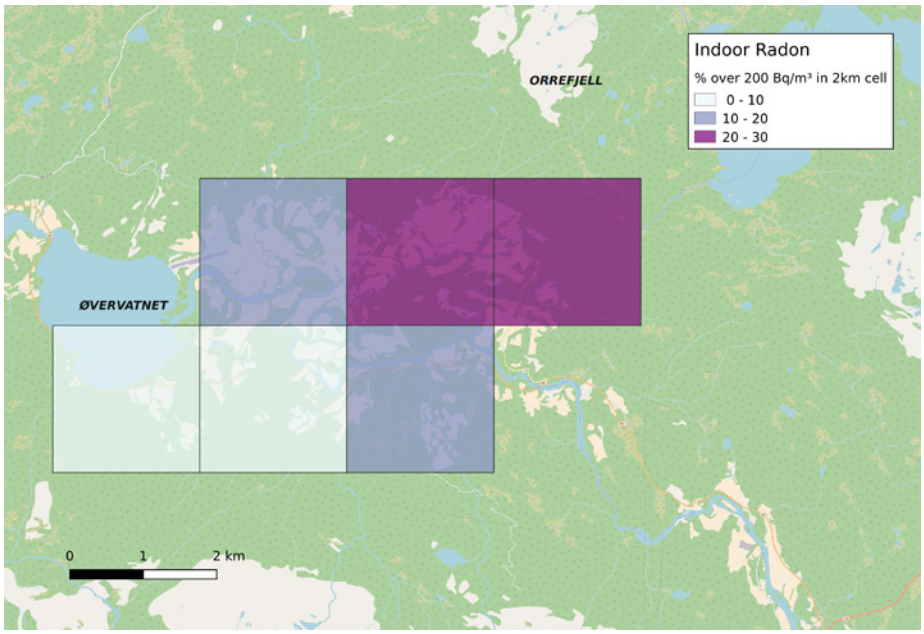
By connecting scientists from various fields, and actively involving local residents, we approached Orrefjell from different angles. As researchers, we all learned something beyond our own discipline. In addition to strengthening the specific knowledge about Orrefjell and radiation exposure routes for humans and animals, the project provided insight into how information is received by the public, which in turn is valuable input to authorities on how to adjust and improve communication.

The Case Orrefjell project was financed by the Fram Centre Hazardous Substances Flagship. ■



Transfer of the radionuclide radium-226 from soil to bilberry heath and berries. The stations are sorted based on soil concentrations of radium-226 with the lowest concentrations to the left. At station 10, the concentrations were considerably higher than at the other stations and the concentrations of radium-226 in soil and bilberry heath are given as numbers. At stations 9, 11 and 12, we did not have enough bilberry material to do radium analyses (nm=not measured).

Percentage of households with radon concentrations above 200 Bq/m³. Each grid is 2x2 km and contains at least five households where living room concentrations of radon were measured in at least two winter months in 2016/2017.



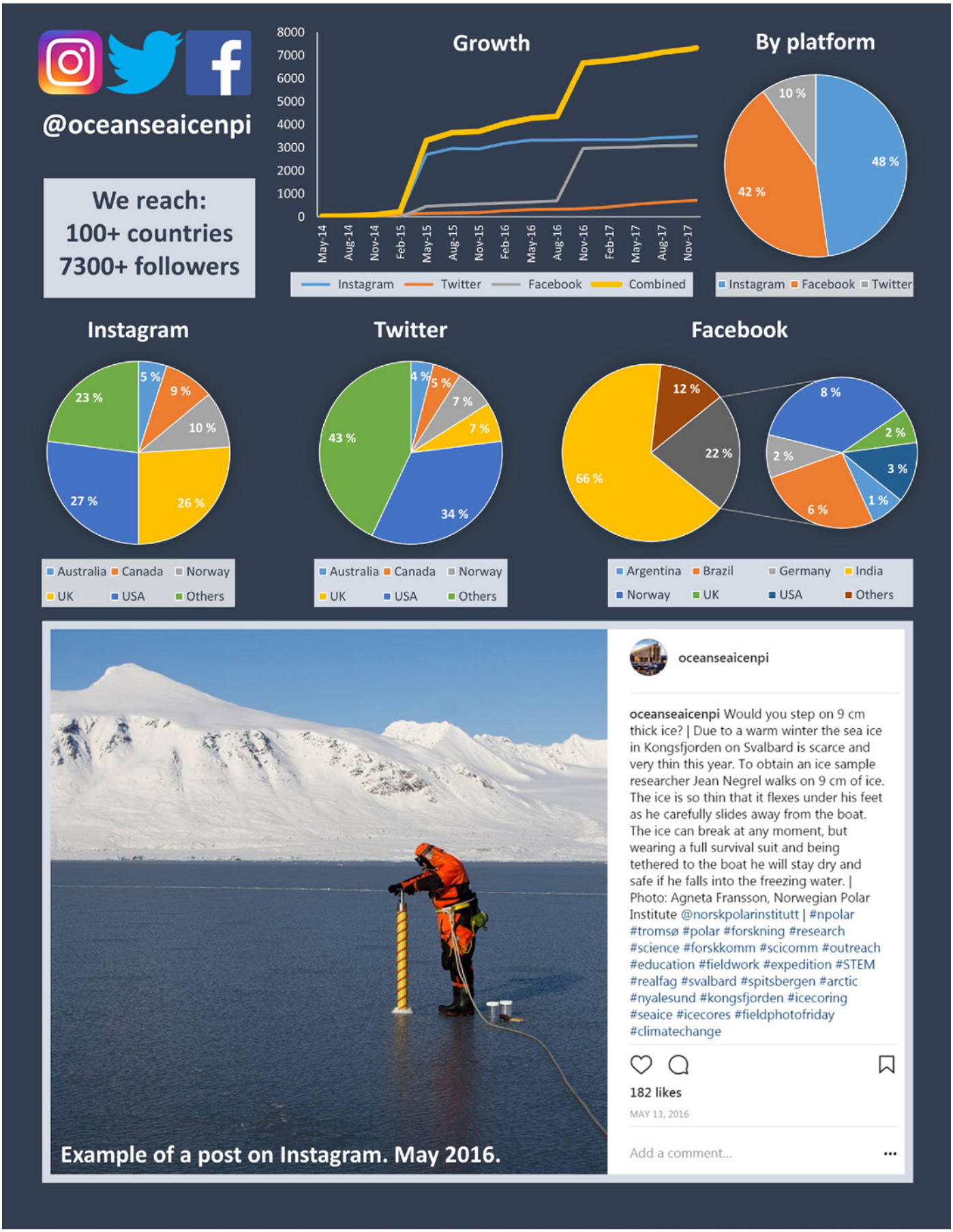
Alexey K. Pavlov, Amelie Meyer, Anja Rösel, Polona Itkin, Jean Negrel, Lana Cohen, Jennifer King, Sebastian Gerland, Stephen R. Hudson, Paul A. Dodd, Laura de Steur, Laura Crews, Marius Bratrein, Stig Mathisen, Mats A. Granskog // Norwegian Polar Institute
Nick Cobbing // National Geographic Magazine

@oceanseaicenpi: communicating polar science via social media

"Science is not finished until it is communicated."
Sir Mark Walport

SCIENCE COMMUNICATION and education are important parts of science, as they increase public scientific literacy, thus benefiting society and people within it. Despite their importance, they are often undervalued and poorly incentivised among researchers, with peer-reviewed publications being the primary measures of academic performance. When it comes to educating and reaching out to the public, youth are a particularly important audience with potential to influence future attitudes and perceptions of important matters, such as environmental issues and climate change. Engaging in outreach activities may potentially attract youth into STEM (Science, Technology, Engineering, and Mathematics) disciplines, including polar sciences. In the face of recent reports that Norwegian young people are becoming less interested in STEM subjects, youth engagement is especially important to maintain the rich polar science tradition and recruit the next generation of researchers.

In addition to conventional outreach efforts such as public lectures, articles in popular magazines, newspapers, and TV documentaries, the increased use of the internet and social media platforms provides a great opportunity to communicate science to various audiences. While individual researchers and large institutions with dedicated communications departments are actively exploring the potential for communicating their science via social media, smaller research teams and labs are still underrepresented but are an important group to connect science with the public.


@oceanseaicenpi
We reach:
100+ countries
7300+ followers
Growth
8000
7000
6000
5000
4000
3000
2000
1000
0
May-14
Aug-14
Nov-14
Feb-15
May-15
Aug-15
Nov-15
Feb-16
May-16
Aug-16
Nov-16
Feb-17
May-17
Aug-17
Nov-17
Instagram
Twitter
Facebook
Combined
By platform
48 %
42 %
10 %
Instagram
Facebook
Twitter
Instagram
5 %
9 %
10 %
26 %
27 %
23 %
Australia
Canada
Norway
UK
USA
Others
Twitter
4 %
5 %
7 %
7 %
34 %
43 %
Australia
Canada
Norway
UK
USA
Others
Facebook
12 %
22 %
66 %
8 %
2 %
3 %
1 %
6 %
2 %
Argentina
Brazil
Germany
India
Norway
UK
USA
Others
oceanseaicenpi
oceanseaicenpi Would you step on 9 cm thick ice? | Due to a warm winter the sea ice in Kongsfjorden on Svalbard is scarce and very thin this year. To obtain an ice sample researcher Jean Negrel walks on 9 cm of ice. The ice is so thin that it flexes under his feet as he carefully slides away from the boat. The ice can break at any moment, but wearing a full survival suit and being tethered to the boat he will stay dry and safe if he falls into the freezing water. | Photo: Agneta Fransson, Norwegian Polar Institute @norskpolarinstitutt | #npolar #tromsø #polar #forskning #research #science #forskkomm #scicomm #outreach #education #fieldwork #expedition #STEM #realfag #svalbard #spitsbergen #arctic #nyalesund #kongsfjorden #icecoring #seaice #icecores #fieldphotofriday #climatechange
182 likes
MAY 13, 2016
Add a comment...
Example of a post on Instagram. May 2016.

POSITIVE EXPERIENCE OF @OCEANSEAICENPI TEAM

We are a small team (fewer than 20 people) of oceanographers, sea ice and atmospheric scientists at the Norwegian Polar Institute. Recognising the importance of science communication, we have shared our research and monitoring activities using Instagram, Twitter and Facebook social media platforms on a regular basis since 2014. These platforms were chosen for their large audiences, rapid growth potential, and widespread use by young people, as well as our own personal experience. As of late 2017, our combined audience has exceeded 7300 followers in more than 100 countries. Our followers are young: on Instagram, most are under 25 years old; 70% are under 25 on Facebook, and 50% are between 25 and 35 years old on Twitter.

In addition to the satisfaction we get from effectively communicating our science, the @oceanseaicenpi initiative has tangibly benefited our careers in several ways. First, we have gained hands-on experience in science communication and outreach, which have become important skills for researchers. Additionally, regular posts across the three social media platforms have increased the visibility of our team's research and activities among other researchers and funding agencies. Highlights of latest peer-review articles co-authored by group members have resulted in elevated Altmetric[1] scores of these publications (on average, more than ten times higher than for publications not highlighted through our accounts). Last but not least, we have become better writers through the preparation of posts on a regular basis, increasing our ability to write concisely, clearly, and in a way that engages the reader. This is a great skill to develop, as our academic careers largely depend on writing.

By sharing our positive experience, we hope to inspire other research groups - within the Fram Centre and beyond - to explore the potential of social media for science communication and education activities. ■

FURTHER READING:

Pavlov AK, Meyer A, Rösel A, Cohen L, King J, Itkin P, Negrel J, Gerland S, Hudson SR, Dodd PA, de Steur L, Mathisen S, Cobbing N, Granskog MA (2018) Does your lab use social media? Sharing three years of experience in science communication. Bulletin of the American Meteorological Society, doi:10.1175/BAMS-D-17-0195.1

LINKS

www.instagram.com/oceanseaicenpi
www.twitter.com/oceanseaicenpi
www.facebook.com/oceanseaicenpi

[1] Altmetrics are metrics and qualitative data that are complementary to traditional, citation-based metrics, and take into account whether research articles have been picked up by media outlets, discussed online, or shared on social media.

Helge M. Markusson // Fram Centre
Elin Vinje Jenssen // Norwegian Polar Institute

New infrastructure in place: more and better research in the High North

Major investments will make 2018 a banner year for research infrastructure in Tromsø. The keyword is workplaces for research and education.

Photo: Harald Grape/UiT

The year started with the opening of the new biology building at UiT The Arctic University of Norway.

"The new biology facilities will inspire learning and stimulate research. The climate research done here will provide guidance for environmental managers and government officials in making policy decisions," says rector Anne Husebekk with pride.

Many of the scientists at the new building carry out biological research related to climate change in the Arctic, and they want to contribute to management policies that alleviate the negative effects of climate change.

The building has 3 600 m^2 of floor space and cost 130 million NOK to build. It has rooms for master's students, group rooms, offices, meeting rooms, laboratories and temperature-controlled research facilities.

The expanded Fram Centre greatly amplifies the research infrastructure in Tromsø.
Photo: Eirik Nicolai Heim / Crux Film

THE FRAM CENTRE HAS EXPANDED

In March of 2018, institutes and organisations started moving into the newly expanded Fram Centre in Tromsø. With this new wing, the Fram Centre expands to almost 25 000 m^2, and 530 people will work within its walls. The official opening ceremony will be held 21 August 2018.

This phase of construction created new offices, laboratories and meeting places. The Institute of Marine Research is making use of its new marine laboratory. The Norwegian Radiation Protection Authority is establishing its own lab specially designed for testing samples from northern regions, while NILU – Norwegian Institute for Air Research just got a brand-new laboratory where they can test for hazardous environmental pollutants.

Among the new tenants in the building are the Institute of Marine Research and BarentsWatch.

In addition, several tenants already in the building will be moving or expanding into new floor space: the Norwegian Radiation Protection Authority, NILU, Fram Centre AS, the Norwegian Polar Institute, and the secretariat of the Arctic Council. Several smaller secretariats will also be moving in.

That also means more space for the tenants who will stay in the original part of the Fram Centre building: Akvaplan-niva AS, the Norwegian Coastal Administration, the Norwegian Institute for Nature Research, the Geological Survey of Norway, and the Norwegian Institute for Cultural Heritage Research.

The old and new buildings create a 900 m^2 indoor space, “Lysgården”, an atrium where research dissemination will take centre stage.

The total cost of the new building is 521 million NOK. Statsbygg, the Norwegian Directorate of Public Construction and Property, was in charge of the

The new research vessel *Kronprins Haakon* will meet researchers' existing and future needs to visit, monitor and collect data in ice-covered and open waters at the far reaches of the globe, north and south, regardless of the season. *Photo: Øystein Mikelborg / Norwegian Polar Institute*

project, and will retain its offices in the old part of the building. The project development firm Hent AS was awarded the turnkey construction contract.

A NEW RESEARCH VESSEL

Norway's newest research vessel, *Kronprins Haakon*, can break through ice to penetrate farther north and south than any Norwegian research vessel in history. The ship is loaded with high-tech equipment that will give us new and unique data on the oceans, climate, and species.

Kronprins Haakon is a floating laboratory and research platform outfitted with first-rate technological equipment. This means she will significantly enhance Norway's fleet of research vessels. She is also the first Norwegian research vessel purpose-built as an icebreaker for use in challenging ice conditions year-round.

With a gross tonnage of 9000 tonnes, a length of 100 metres and a width of 21 metres, this vessel will accommodate 55 people – scientists, students and crew – in 38 cabins.

The Norwegian Polar Institute is the formal owner of *Kronprins Haakon*. The Institute of Marine Research operates the ship, while UiT The Arctic University of Norway is the primary user. She was built at the Italian Fincantieri shipyard and launched in Italy in February 2017. Norway has so far invested 1.4 billion NOK in this important piece of research infrastructure. ■

Elin Vinje Jenssen // Norwegian Polar Institute
Photo: Adolf Hoel // Norwegian Polar Institute

Conservationist Hanna Resvoll-Holmsen – Svalbard's first female researcher

Botanist Hanna Resvoll from Vågå in Oppland is on the deck of the vessel *Holmengraa*, sailing past Amsterdamøya at the northwest tip of Spitsbergen. Geologist Gunnar Holmsen stands beside her. It is 1908 and the two researchers are heading north for an expedition to Svalbard – the one that became so important to Norway that it is now simply called "The Svalbard Expedition".

The man next to Hanna was not just anybody. Gunnar Holmsen would later become her husband. But first these scientists would explore Svalbard, each focusing their own discipline.

Resvoll herself was not just anybody either. She was the first Norwegian woman who did research in Svalbard. Resvoll worked at the time when Norway's most famous polar heroes Nansen and Amundsen were exploring the polar regions. Like them, Hanna was a pioneer, but unlike them, she has reaped little fame outside her own discipline – undeservedly little, many will argue. The work Hanna Resvoll carried out in Svalbard is now considered the start of Norway's scientific efforts in the archipelago, and it contributed to Svalbard becoming part of Norway in 1920.

Hanna was a true professional, but also a mother. Before she went to Svalbard, she had been married and divorced – which was quite unusual at that time – and she later remarried, this time to Gunnar Holmsen.

Hanna Resvoll-Holmsen paved the way for women, both in academia and in polar research. She was the first woman to attain a doctoral degree in botany in Norway, and later became the first female lecturer in phytogeography. Hanna's interest in high alpine plants was what attracted her to Spitsbergen. Often working entirely alone, she crossed glaciers, climbed steep mountains and walked along shores, charting, photographing and collecting arctic plants and fossils. She was the first to document Svalbard's plants in colour photographs, and in 1927 she published what later became a classic in the field of botany: "Svalbard flora".

Resvoll-Holmsen's desire to preserve nature in Svalbard and mainland Norway is a recurring theme throughout her work, and she contributed to establishing lasting protection of vulnerable species, historic sites and plants. She is often hailed as our first modern conservationist.

Hanna Resvoll-Holmsen is being honoured with a monumental work of art by Anne-Karin Furunes, to be placed in the atrium of the Fram Centre. Well worth a visit for anyone passing through Tromsø. Please contact the Fram Centre reception for information. ■

Projects in the Fram Centre Flagships for 2017

Effects of climate change on sea and coastal ecology in the north (Fjord and Coast)

Physical-biological coupling: Oceanography and habitat use by predators and their prey

RESEARCH AREAS/PROJECT TITLES	PROJECT LEADER	PARTICIPATING INSTITUTIONS	E-MAIL PROJECT LEADER
Impact of massive winter herring abundances on the Kaldfjorden environment	Angelika Renner	IMR, ApN, NIVA	angelika.renner@imr.no
The impact of oceanic inflow and glacial runoff on the carbon budget in Kongsfjorden using field and model data	Melissa Chierici	IMR, NPI, UNIS	melissa.chierici@imr.no
The role of the harbour porpoise in Norwegian coastal marine communities	Ulf Lindstrøm	IMR, UiT, ApN, NAMMCO, NTNU, UoStA	ulf.lindstroem@imr.no
Examining the role of fish-falls on ecosystem processes in highly exploited fjord systems	Paul Renaud	ApN, NIVA, IMR, HWU, NOC	paul.renaud@akvaplan.niva.no
Seabird habitat use and migration strategies	Børge Moe	NINA, ApN, UiT, NILU, UNIS, NPI, NTNU, UoO, CNRS, LRU, UoGr, IMARES, AU, AARI, UoF, CEH BAS, UAF, UoIs, UTu	borge.moe@nina.no
The coastal migratory behaviour of anadromous fish in relation to environmental parameters	Guttorm N. Christensen	ApN, UiT, NIVA, FOC, UoWa	gnc@akvaplan.niva.no
Research on maritime cultural heritage in coastal Arctic regions	Sanne Bech Holmgaard	NIKU, NINA, TCD	sanne.holmgaard@niku.no
Timing of reproduction in seabirds: Population dynamics, climate and lower trophic levels	Zofia Burr	UNIS, NPI, NINA, UiT, ApN, IMR, BS	zofia.burr@gmail.com
Ecological and commercial implications of extreme winter arrivals of herring and whales into North-Norwegian fjord systems	Martin Biuw	IMR, NINA, UiT	martin.biuw@imr.no
Mapping Sea Ice Characteristics relevant for Arctic Coastal Ecosystems	Sebastian Gerland	NPI, MET, NORUT, UiT	sebastian.gerland@npolar.no

Structure, function and change in Arctic and boreal fjord ecosystems

Recovery of coastal kelp ecosystems – driven by climate change or predators?	Hartvig Christie	NIVA, IMR, ApN, NBIC	hartvig.christie@niva.no
Salmon at sea in a changing world	Martin Svenning	NINA, UiT, LUKE, UTu, FOC, UoWa	martin.svenning@nina.no
Carbon flux dynamics in ice-free versus ice-covered Svalbard fjords during the last decade: Exploring the effects of sea ice variability on the downward flux of biogenic particles	Gerald Darnis	ApN, UiT, UNIS, NPI, UoLa SAMS	gerald.darnis@akvaplan.niva.no
The Arctic scallop *Chlamys islandica* as a biosensor for detection of effects of climate upon ecosystem functioning and anthropogenic impact in Svalbard	Lionel Camus	ApN, UNIS, UiT, CNRS	lionel.camus@akvaplan.niva.no
Pan arctic connectivity of zooplankton populations: The case of *Pseudocalanus*	Claudia Halsband	ApN, UNIS, UiT, UoCo, UoAF	claudia.halsband@akvaplan.niva.no
Marine snow, pelagic-benthic coupling and the impact of the harpacticoid copepod *Microsetella norvegica*, and other agents in a high-latitude fjord	Camilla Svensen	UiT, NPI, IMR, DTU, AWI	camilla.svensen@uit.no
Marine base maps for the Porsanger Fjord	Aivo Lepland	NGU, IMR, NRPA	aivo.lepland@ngu.no
Climate-driven regime shifts in arctic rocky-bottom communities	Raul Primicerio	UiT, ApN, UNIS	raul.primicerio@uit.no
Meroplankton biodiversity and seasonal dynamics	Janne Søreide	UNIS, ApN, UoGd, PAS	janne.soreide@unis.no

Sea ice in the Arctic Ocean, Technology and Governance (Arctic Ocean)

Sea ice, ecosystems and models

RESEARCH AREAS/PROJECT TITLES	PROJECT LEADER	PARTICIPATING INSTITUTIONS	E-MAIL PROJECT LEADER
Developing modelling tools to understand the role of solar radiation to sea ice mass balance in a seasonally ice covered Arctic	Mats Granskog	NPI, MET, UiT	mats.granskog@npolar.no
Long-term variability and trends in the Atlantic water inflow region	Paul A. Dodd	NPI, IMR, UNIS, UiT, IOPAS, WHOI	paul.dodd@npolar.no
Mesoscale modelling of ice, ocean and ecology of the Arctic Ocean	Tore Hattermann	ApN, IMR, NPI, SINTEF, MET	tore.hattermann@akvaplan.niva.no
Ecosystem modelling of the Arctic Ocean around Svalbard	Pedro Duarte	NPI, ApN, NIVA, UiT	pedro.duarte@npolar.no
Holocene ocean and sea ice history at north-east Svalbard – from past to present warm extremes	Katrine Husum	NPI, UiT, UNIS, BAS, BCCR/UoB, NCAOR, UoP, UCL	katrine.husum@npolar.no
Using tracers, atmospheric indices and model output to explain changes in the Arctic Ocean inflow and outflow through Fram Strait	Paul A. Dodd	NPI, NRPA, ApN, IMR, OASYS	paul.dodd@npolar.no
Assessment of ecosystem vulnerability and functioning in ice-affected waters	Lis L. Jørgensen	IMR, UiT, UNIS, ApN	lis.lindal.joergensen@imr.no
Barents Sea harp seals in a changing Arctic	Kjell T. Nilssen	IMR, UiT, ApN, PINRO, SMR, SAMS	kjell.tormod.nilssen@imr.no

Driving forces and development of new industry

Information systems in the Arctic Ocean: Drivers, architecture, and effects on the development of marine economic activities	Maaike Knol	UiT, NPI, MET, WU, SCNN	maaike.knol@uit.no

Technology

Ice floe interaction with ships and waves	Karl Gunnar Aarsæther	SINTEF, UiT, TO, Opilio Inc.	Karl.Gunnar.Aarsather@sintef.no

Ocean acidification and ecosystem effects in northern waters (Ocean acidification)

Understanding the physical and chemical mechanisms controlling ocean acidification (OA) in Arctic waters – past, present and future

RESEARCH AREAS/PROJECT TITLES	PROJECT LEADER	PARTICIPATING INSTITUTIONS	E-MAIL PROJECT LEADER
Current OA state and variability	Agneta Fransson	NPI, NIVA, IMR, UiT, UNIS, BedIn	agneta.fransson@npolar.no
Biogeochemical drivers and climate change on OA	Agneta Fransson	NPI, IMR, UoH, BedIn	agneta.fransson@npolar.no

Biological effects of Ocean Acidification (OA)

Physiological challenges of OA on copepods	Howard Browman	IMR, NPI, BOS, UoM, CU, RU	howardb@imr.no
Transgenerational effects of OA	Caludia Halsband	ApN, NPI	claudia.halsband@akvaplan.niva.no
Evolutionary rescue from Arctic OA	Haakon Hop	NPI, UNIS, UQAR, UoGo	haakon.hop@npolar.no
Ontogeny and physiological constraints on early life history stages of *Lophelia pertusa*	Johanna Järnegren	NINA, FSU	johanna.jarnegren@nina.no
Pteropod shell thickness and composition in different regimes	Agneta Fransson	NPI, IMR, JAMSTEC, PAS	agneta.fransson@npolar.no

Coupled climate-ecosystem-acidification modelling from organism to basin

Validation and comparison of coupled physical-biogeochemical models	Philip Wallhead	NIVA, IMR	philip.wallhead@niva.no
Investigate pelagic ecosystem sensitivity and feedbacks to Arctic OA	Philip Wallhead	NIVA, IMR	philip.wallhead@niva.no

Socio-economic consequences and management options

Ecosystem effects of OA in northern waters: Socio-economic consequences and management options	Jannike Falk-Andersson	NORUT, NIVA, IMR, UoQ	Jannike.Falk-Andersson@norut.no

Effects of climate change on terrestrial ecosystems, landscapes, society and indigenous peoples (Terrestrial)

Vegetation state change and herbivore management

RESEARCH AREAS/PROJECT TITLES	PROJECT LEADER	PARTICIPATING INSTITUTIONS	E-MAIL PROJECT LEADER
After-the-Pest: Ecosystem transitions following insect pest outbreaks induced by climate change in the European high north	Jane Uhd Jepsen	NINA, UiT	jane.jepsen@nina.no
Hunt for the birch larva: A citizen science initiative for mapping of an invasive species	Jane Uhd Jepsen	NINA, UiT	jane.jepsen@nina.no
Moose in Finnmark - spatial ecology and management in a changing landscape	Erling Meisingset	NIBIO, UiT, NINA	erling.meisingset@nibio.no

Ecosystem effects of extreme climate events and changing seasons

Use of remote sensing for increased precision in forage production	Marit Jørgensen	NIBIO, NORUT, NINA	marit.jorgensen@nibio.no
Ecosystem stress from the combined effects of winter climate change and air pollution - how do the impacts differ between biomes?	Jarle W. Bjerke	NINA, MET, NORUT	jarle.werner.bjerke@nina.no
Health and infectious diseases in semi-domesticated reindeer in a changing climate	Morten Tryland	UiT, VET, NINA, NORUT, EINRC	morten.tryland@uit.no
North state TromSAR - climate variability in SAR land cover monitoring	Jörg Haarpaintner	NORUT, NINA, NCA	Joerg.Haarpaintner@norut.no
Arctic growing season length: Remote sensing of growing season length on Svalbard's Arctic tundra in relation to snow melt date	Elisabeth Cooper	UiT, NINA, NORUT	elisabeth.cooper@uit.no

Capacity for adaptation in indigenous people and local societies

Social norms of equality and cooperation: A comparative approach	Marius Warg Næss	NIKU, NINA, SUAS	marius.naess@niku.no
Land use change among indigenous pastoralists: Mapping historic land use in northern landscapes	Stine Barlindhaug	NIKU, NMBU, UiT	stine.barlindhaug@niku.no

Adaptive management of ecosystem services

Socio-ecologic modelling of reindeer population dynamics at multiple spatial scales using a structural equation modelling approach	Bård-Jørgen Bårdsen	NINA, NIKU, NMBU	bard.jorgen.bardsen@nina.no
Sustainable management of renewable resources in a changing environment: An integrated approach across ecosystems	John-André Henden	UiT, UoO, NTNU, NINA, NPI	john-andre.henden@uit.no
Taking into account heterogeneity in ecosystem services monitoring and climate change adaptation	Vera Hausner	UiT, NINA, USU, CPSU	vera.hausner@uit.no
Yamal ecosystem - collaboration for monitoring of climate related ecosystem change on Yamal, Russia	Dorothee Ehrich	UiT, NPI, NINA, RAS	dorothee.ehrich@uit.no

Observation systems for climate effects

COAT: Climate-ecological-Observatory-for- Arctic-Tundra	Rolf Ims	UiT, NINA, NPI, UNIS, MET	rolf.ims@uit.no

Outreach

Book: Snowy Owl (*Bubo scandiacus*)	Karl-Otto Jakobsen	NINA	karl.o.jacobsen@nina.no

Hazardous substances – effects on ecosystems and human health (Hazardous substances)

The effects of contaminants on human health and Arctic communities

RESEARCH AREAS/PROJECT TITLES	PROJECT LEADER	PARTICIPATING INSTITUTIONS	E-MAIL PROJECT LEADER
Assessing contaminant exposure in school children using novel and non-invasive wristbands	Linda Hanssen	NILU, ApN, UiT	linda.hanssen@nilu.no
Human biomonitoring and mechanistic modelling of organic compounds across time (1986-2007) in 30 year old Tromsø men	Therese H. Nøst	NILU, ApN, UiT, UNN, INSPQ	therese.h.nost@uit.no
Effect of the exposure to perfluoro-octanoic acid during gestation in mice on the immune response of offspring to pertussis (whooping cough) vaccination	Jacques Godfroid	UiT, NILU	jacques.godfroid@uit.no

The fate and effects of contaminants in Northern ecosystem in combination with climate change, natural and anthropogenic stressors

Atmospheric inputs of organic contaminants of emerging concern to the Arctic and possible implications for ecosystem exposure	Ingjerd S. Krogseth	ApN, NILU	isk@nilu.no
Giants of the ocean – affected by anthropogenic pollutants?	Heli Routti	ApN, NPI, NILU, UoB, UoS	heli.routti@npolar.no
Impacts of environmental contaminants and natural stressors on northern raptors	Jan Ove Bustnes	NINA, NILU, NTNU, UiT, UoA, AU, UoMu	jan.o.bustnes@nina.no
Multi-stress relationships in seabird populations: Interactions between natural stressors and environmental contaminants	Jan Ove Bustnes	NINA, NPI, NILU, ApN, UoO, CEBC	jan.o.bustnes@nina.no
Contaminant levels and effects in killer (*Orcinus orca*) and humpback whales (*Megaptera novaeangliae*) present in Northern-Norway	Jenny Bytingsvik	ApN, NIVA, NILU, UiT, IMR , NPI, VU	jby@akvaplan.niva.no
Habitat and dietary specific accumulation of methylmercury in Arctic charr	Hans Fredrik V. Braaten	NIVA, ApN, NINA, UiT	HansFredrik.VeitebergBraaten@niva.no
Endocrine disruptor sex change	Marc Anglès d'Auriac	NIVA, ApN, UiT	marc.angles.dauriac@niva.no
Impact of climate sensitive life history traits on uptake and maternal transfer of pollutants in Arctic breeding geese	Øystein Varpe	UNIS, ApN, NIVA, UoO, NILU, NINA, WWT, UoGr	oystein.varpe@unis.no

Impact from industrial development and urbanization in the North – Fate and effects of pollutants on Arctic ecosystems

Microplastics from artificial sports pitches: Composition, degradation and biological interactions	Dorte Herzke	NILU, ApN, SINTEF, IMR, UoBe	dorte.herzke@nilu.no
Impact of Arctic urbanization on the occurrence of new "urban" contaminants in the Norwegian Arctic	Pernilla Bohlin Nizzetto	NILU, NIVA, ApN, RECETOX	pbn@nilu.no

Risk governance – Communicating and applying research results

Case Orrefjell: Evaluation of possible adverse effects related to living in an area with enhanced levels of naturally occurring radioactive material	Louise Kiel Jensen	NRPA, NORUT, NMBU, NGU	louise.kiel.jensen@nrpa.no
Bringing the Arctic perspective to global conventions – the role of science in the negotiations towards the adoption of the Minamata Convention	Froukje Maria Platjouw	NIVA, ApN, UiT	fmp@niva.no

Environmental impacts of industrial activity in the north (MIKON)

Knowledge basis for ecosystem based management

RESEARCH AREAS/PROJECT TITLES	PROJECT LEADER	PARTICIPATING INSTITUTIONS	E-MAIL PROJECT LEADER
Managing variable environmental values: Holistic integrations for Arctic coastal-marine sustainability	Ellen Øseth	NPI, IMR	oseth@npolar.no
Ecosystem vulnerability assessment of resources in the Barents Sea	Raul Primicerio	UiT, IMR, ApN	raul.primicerio@uit.no
Ocean Health in Transition: Indices of ocean health under shifting ecological and societal conditions	Per Fauchald	NINA, UiT, NIVA, IMR, NORUT, Nofima	per.fauchald@nina.no

Consequences for organisms and ecosystems

Development of model for prediction of eutrophication and sedimentation from fish cage farms	Ole Anders Nøst	ApN, NORUT, UiT, NIVA	ole.anders.nost@akvaplan.niva.no
Fate and impact of mine tailings on marine Arctic ecosystems	Anita Evenset	ApN, NGU, IMR, NORUT, NRPA, SIO, UoG	anita.evenset@akvaplan.niva.no
Arctic Cetaceans and Ocean Noise	Kit Kovacs	NPI, UiT, UNIS	kit.kovacs@npolar.no
How to avoid conflicts between wild and farmed salmonids? Finding good locations for aquaculture	Jenny L.A. Jensen	ApN, UiT, IMR	jenny.jensen@akvaplan.niva.no
Seabird moulting and chick rearing area in relation to planned oil activity in the southeastern Barents Sea	Kjell Einar Erikstad	NINA, NPI, IMR, CEH	kjell.erikstad@nina.no

Consequences for cultural heritage and society

Sea urchin harvest: Ecosystem recovery, integrated management of social-ecological system, ecosystem service and sustainability	Wenting Chen	NIVA, UiT, Nofima, UoC	wenting.chen@niva.no
The impact of extractive industries and tourism on socioecological dynamics in the Arctic	Vera Hausner	UiT, NINA	vera.hausner@uit.no
Ecosystem services and coastal governance	Einar Eythorsson	NIKU, Nofima	einar.eythorsson@niku.no
Indigenous-industry governance interactions in the Arctic: Environmental impacts and knowledge basis for management	Camilla Brattland	UiT, NIKU	camilla.brattland@uit.no

ABBREVIATIONS

AARI: The Arctic and Antarctic Research Institute; **ApN:** Akvaplan-niva Inc.; **AU:** Aarhus University; **AWI:** Alfred Wegener Institute; **BAS:** British Antarctic Survey; **BC:** Bates College; **BedIn:** Bedford Institute; **BOS:** Bigelow Laboratory for Ocean Science; **BS:** The Bjerknes Centre; **CEBC:** Centre d'Etudes Biologiques de Chizé; **Cedre:** Centre of Documentation, Research and Experimentation on Accidental Water Pollution; **CEH:** The Centre for Ecology & Hydrology; **CNRS:** The National Center for Scientific Research; **CRRL:** Control/Robotics Research Laboratory (NYU Polytechnic School of Engineering); **CU:** Clemson University; **DTU:** Technical University of Denmark; **FMI:** Finnish Meteorological Institute; **FNI:** Fridtjof Nansen Institue; **FOC:** Fisheries and Oceans Canada; **FSU:** Florida State University; **IDAEA-CSIC:** Institute of Environmental Assessment and Water Research – Spanish Council for Scientific Research; **IMARES:** Institute for Marine Resources & Ecosystem Studies; **IMR:** Institute of Marine Research; **INSPQ:** Public Health Expertise and Reference Centre - Québec; **IVM:** Institute for Environmental Studies; **JAMSTEC:** Japan Agency for Marine-Earth Science and Technology; **LIENSs:** Littoral, Environment and Societies, La Rochelle University; **LRU:** La Rochelle University; **LUKE:** Natural Resources Institute Finland; **MET:** The Norwegian Meteorological Institute; **MU:** Massey University; **NAMMCO:** North Atlantic Marine Mammal Commission; **NBIC:** Norwegian Biodiversity Information Centre; **NCA:** The Norwegian Coastal Administration; **NCAOR:** National Centre for Antarctic and Ocean Research; **NGU:** Geological Survey of Norway; **NIBIO:** The Norwegian Institute of Bioeconomy Research; **NIKU:** The Norwegian Institute for Cultural Heritage Research; **NILU:** Norwegian Institute for Air Research; **NINA:** Norwegian Institute for Nature Research; **NIVA:** Norwegian Institute for Water Research; **NMBU:** Norwegian University of Life Sciences; **Nofima:** The Norwegian Institute of Food, Fisheries and Aquaculture Research; **NORUT:** Northern Research Institute; **NPI:** Norwegian Polar Institute; **NRPA:** Norwegian Radiation Protection Authority; **NTNU:** Norwegian University of Science and Technology; **OASYS:** Ocean Atmosphere Systems - Research; **PAS:** Polish Academy of Sciences; **PINRO:** Polar Research Institute of Marine Fisheries and Oceanography; **RAS:** Russian Academy of Sciences; **RECETOX:** Research Centre for Toxic Compounds in the Environment; **RU:** Ryerson University; **SAMS:** The Scottish Association for Marine Science; **SCNN:** Science Centre of Northern Norway; **SINTEF:** The Company for Industrial and Technological Research; **SIO:** Scripps Institution of Oceanography; **SRCES-RAS:** Scientific Research Center for Ecological Safety - Russian Academy of Sciences; **SU:** Stockholm University; **TCD:** Trinity College Dublin; **TI:** Thule Institute; **TM:** Tromsø Municipality; **TO:** Troms Offshore; **UAF:** University of Alaska - Fairbanks; **UiT:** UiT The Arctic University of Norway; **UNIS:** The University Centre in Svalbard; **UNN:** University Hospital of North Norway; **UoA:** University of Antwerpen; **UoC:** University of California; **UoCa:** University of Calgary; **UoF:** University of Freiburg; **UoG:** University of Gent; **UoGd:** University of Gdańsk; **UoGo:** University of Gothenburg; **UoGr:** University of Groningen; **UoH:** University of Hokkaido; **UoIs:** University of Island; **UoL:** University of Leicester; **UoLa:** University of Laval; **UoM:** University of Maine; **UoMu:** University of Murcia; **UoNB:** University of New Brunswick; **UoO:** University of Oslo; **UoOu:** University of Oulu; **UoQ:** University of Queensland; **UoR:** University of Reading; **UoStA:** University of St. Andrews; **UoWa:** University of Waterloo; **UQAR:** Université du Québec à Rimouski; **UT:** University of Texas; **UTu:** University of Turku; **VU:** Vrije University Amsterdam; **WHOI:** Woods Hole Oceanographic Institution; **WU:** Wageningen University

Recent doctorates

27 February 2017

Elena Artamonova

Mass cultivation of some common coldwater diatoms (Bacillariophyceae): lipids vs. growth conditions

This study investigates diatoms as sustainable sources for omega-3 fatty acids, needed in salmon aquaculture and as ingredients in nutraceuticals for humans. Northern cold-water diatoms were investigated in terms of lipid and fatty acid composition, and the effects of cultivation parameters (light, temperature, CO_2/pH) on lipogenesis were studied. The research shows that temperature decrease together with moderate light intensities may trigger accumulation of polyunsaturated fatty acids (including physiologically requisite EPA) in diatom species. Total lipid content and production of certain fatty acids in diatoms cell may be enhanced by CO_2 aeration. However, diatoms' metabolic responses were highly variable and species-specific.

Link to the thesis: https://munin.uit.no/handle/10037/10300

UiT The Arctic University of Norway
Faculty of Biosciences, Fisheries and Economics
The Norwegian College of Fishery Science

5 May 2017

Allison Michelle Bailey

The fate of a key Arctic copepod in future ocean acidification: Integrating molecular, organismal, and evolutionary thinking in the face of climate change

This thesis examines the effects of projected levels of ocean acidification on the physiology of the copepod *Calanus glacialis*, a key component of Arctic marine ecosystems. Several methods reveal the effects of low pH in combination with other stressors (food availability) and across geographically distant sub-populations (to predict their capacity for adaptation or acclimation in the future). Young stages of the copepod were tolerant to realistic future pH levels, whereas young copepodite stages appeared to suffer from higher energetic cost at low pH. This detrimental effect differed between geographically and potentially genetically isolated sub-populations: those that lived in a low pH environment tolerated it better, indicating that *C. glacialis* may be able to alleviate detrimental effects over time.

Link to the thesis: https://munin.uit.no/handle/10037/10963

UiT The Arctic University of Norway
Faculty of Biosciences, Fisheries and Economics
Department of Arctic and Marine Biology

Joint supervision with the Norwegian Polar Institute and Akvaplan-niva

5 April 2017

Xuan Bich Bui

Economic analysis of Marine Protected Areas: Bioeconomic Modeling and Economic Valuation Approaches

Marine protected areas (MPAs) are often established for conservation objectives. This thesis attempts to analyze some of the benefits of MPAs in specific situations. It describes how MPAs can be used as a management tool to solve economic conflicts between ocean users, more specifically aquaculture and wild commercial fisheries competing for the use of the same species. An integrated bioeconomic model is developed for analyzing the impacts

of an MPA on aquaculture-fisheries interactions. The thesis also identifies benefits from MPA-based tourism activities by using the discrete choice experiment method. The empirical analysis is applied to an MPA in Vietnam.

Link to the thesis: https://munin.uit.no/handle/10037/10946

UiT The Arctic University of Norway
Faculty of Biosciences, Fisheries and Economics
The Norwegian College of Fishery Science

28 February 2017

Xiangcai Chen

A study of dayside open/closed field line boundary dynamics using simultaneous ground-based optical and HF radar observations

Particle energy from the Sun enters the Earth's atmosphere through a process called reconnection. This process involves connecting the magnetic fields of the solar wind (where one can find escaped particles from the Sun) with the magnetic fields of the Earth. When reconnection happens, it creates an "open" geomagnetic field line with one foot point on the Earth's surface, and the other ultimately connected to the Sun. The Earth also has closed field lines with both foot points on the Earth's surface (dipole shape). The open field line contains energetic particles from the Sun. Chen has studied this process with two ground-based instruments: an optical instrument that can measure the intensity of the aurora (the Meridian Scanning Photometer) and a radar that can measure the velocity of particles in the Earth's atmosphere (the SuperDARN radar). Using these two instruments, Chen has looked at where the boundary between open and closed geomagnetic field lines occurs. This is significant in order to understand the nature of reconnection – the important process for energy transfer between the Sun and the Earth's atmosphere.

University of Oslo
Faculty of Mathematics and Natural Sciences
Department of Physics

Joint supervision with the Department of Arctic Geophysics, University Centre in Svalbard

7 December 2017

Helena Kling Michelsen

Seasonal and spatial dynamics of meroplankton in a sub-Arctic fjord with additional focus on larvae of the invasive red crab

Many benthic marine organisms produce pelagic larvae, meroplankton. The benthic red king crab, an important economic resource, also threatens the ecosystem. This thesis studied the seasonal and spatial dynamics of meroplankton at high latitudes, identifying environmental variables responsible for spawning, and the potential role of meroplankton, including red king crab larvae. Samples from Porsangerfjord, Norway, showed greatest meroplankton abundance and number of taxa in spring and summer, correlating with increased chlorophyll a and temperature. Meroplankton contributed strongly to the mesozooplankton community, suggesting their importance in the pelagic food web. Red king crab larvae were released continually over six months, which ensures that some larvae will have favourable conditions. Along with the wide environmental tolerance of larvae and adults, this gives red king crabs potential to expand in Norway and north into Svalbard waters.

Link to the thesis: https://munin.uit.no/handle/10037/11779

UiT The Arctic University of Norway
Faculty of Biosciences, Fisheries and Economics
Department of Arctic and Marine Biology

10 October 2017

Harald Øverli Eriksen

Combining Satellite and Terrestrial Interferometric Radar Data to Investigate Surface Displacement in the Storfjord and Kåfjord area, Northern Norway

In this project, multi-geometrical radar datasets from ground- and satellite-based radar have been combined to form two-dimensional (2D) and three-dimensional (3D) surface displacement vectors, creating new ways to interpret surface deformation. By plotting the resulting 2D and 3D surface displacement vector datasets in map and cross-sections, we interpret displacement at the land-

form- and landscape-scale. In contrast with single radar datasets, using 2D and 3D surface displacement vectors together with topography enables us to calculate different kinematic diagnostic parameters that can be used as tools for interpretation of displacement patterns.

Link to the thesis: https://munin.uit.no/handle/10037/11679

UiT The Arctic University of Norway
Faculty of Science and Technology
Department of Geology

19 September 2017

Anne Elina Flink

Glacier dynamics in the fjords of Svalbard, inferred from submarine landforms and marine sediment cores

This thesis reconstructs late Weichselian, deglacial and Holocene glacial history, focusing on the fjords of eastern Spitsbergen. It is based on high-resolution multibeam data, shallow acoustic (chirp) data, marine sediment cores, historical maps and aerial/satellite images. Submarine landforms indicate increasing ice flow velocities from inner to outer fjords and the shelf. The northeastern shelf edge was deglaciated rapidly by ice lift-off, whereas shallower areas had slower retreat with minor re-advances. In early- to mid-Holocene, tidewater glaciers on the east coast surged at least once, unlike the west coast glaciers. The early Holocene advance in Mohnbukta has been attributed to rapid climatic and environmental change at the end of deglaciation, leading to dynamic disequilibrium and a jump into surge-mode. This indicates a more important role of climate in the evolution of general surge patterns than previously presumed.

Link to the thesis: http://bora.uib.no/handle/1956/16733

University of Bergen
Faculty Mathematics and Natural Sciences
Department of Earth Science

Joint supervision with the Department of Arctic Geology University Centre in Svalbard

17 March 2017

Ane Schwenke Fors

Investigations of summer sea ice with X and C-band multi-polarimetric synthetic aperture radar (SAR)

This thesis explores the possibilities and limitations of using space-borne multi-polarimetric SAR (both X- and C-band) in summer sea ice investigations. It utilizes data sets collected in 2011 (Fram Strait) and 2012 (north of Spitsbergen). Both sets combine satellite SAR scenes with co-located ground and airborne measurements. The study explores the summer sea ice type discrimination ability and temporal consistency of six polarimetric SAR features, and tests an automatic segmentation algorithm based on the features. The algorithm successfully segments the C-band SAR scenes into different sea ice types, but performs poorly in X-band. Several C-band polarimetric SAR features correlate with sea ice macro-scale surface roughness, but the relationships are sensitive to incidence angle, meteorological conditions, and micro-scale surface roughness. The findings differ from previous studies in other seasons, demonstrating that SAR sea ice surface roughness signatures change with season and sea ice type.

Link to the thesis: https://munin.uit.no/handle/10037/10723

UiT The Arctic University of Norway
Faculty of Science and Technology
Department of Physics and Technology

Joint supervision with the Norwegian Polar Institute

9 May 2017

Julie Cornelius Grenvald

Understanding winter patterns of zooplankton diel vertical migration (DVM) in a high Arctic fjord (Kongsfjorden, Svalbard)

Recent Arctic studies contradict the long-held paradigm of winter quiescence and document activity in the marine food web even during the darkest months of winter. Diel Vertical Migration (DVM) of zooplankton during the polar night has attracted much attention. Grenvald's PhD

thesis examines the general patterns of DVM during the polar night in Svalbard waters, identifying which species actually migrate and why they conduct these energetically costly migrations. The results show that polar night DVM is complex, involving several migration patterns. Zooplankton net sampling, in parallel with acoustics, revealed krill as the dominant species behind migratory patterns. Molecular and electrophysiological experiments showed that ambient light levels rather than endogenous genetic control governed winter migration patterns.

UiT The Arctic University of Norway
Faculty of Biosciences, Fisheries and Economics
Department of Arctic and Marine Biology

Joint supervision with University Centre in Svalbard

21 March 2017

Ulrike Grote

Calanus glacialis and *C. finmarchicus* in a warming Arctic. Implications of increasing temperature at the individual and population level

Climate change is likely to have dissimilar effects on species. This thesis investigates physiological processes such as feeding, egestion, respiration, and egg production rates of *C. glacialis* in relation to temperature (0-10°C). One experiment showed linear increases in ingestion and egestion with temperature, while another showed thermal optima for ingestion (2.5°C) and respiration (6°C). Metabolic mismatch between carbon ingestion and respiration above 6°C might impair growth and survival. The effects of temperature on *C. glacialis* and *C. finmarchicus* populations were probed using the SINMOD model. The simulation suggests that rising temperature would increase *C. finmarchicus* biomass and net production in the southern Barents Sea, whereas those of *C. glacialis* will likely increase in the northern Barents Sea, but only up to summer seawater temperatures of 5-6°C.

Link to the thesis: https://munin.uit.no/handle/10037/10739

UiT The Arctic University of Norway
Faculty of Biosciences, Fisheries and Economics
Department of Arctic and Marine Biology

Joint supervision with SINTEF

17 February 2017

Charmain Hamilton

Challenges for ice-associated top trophic Arctic animals in a changing climate

Arctic sea-ice extent is declining rapidly. Arctic marine mammals and seabirds, such as ringed seals, polar bears and ivory gulls, are dependent on sea ice and are likely negatively impacted by sea-ice declines. These three species are linked: ringed seals are the main prey of polar bears and ivory gulls scavenge on polar bear kills. This PhD project examines how ongoing declines in sea ice around Svalbard, Norway, are affecting polar bears, ringed seals and ivory gulls as individual species and as an interlinked group. The decline in coastal sea-ice has likely made it more difficult for polar bears to hunt ringed seals; polar bears now spend less time near tidal glacier fronts, where ringed seals are primarily found, and more time near ducks and geese. Further retreat of the offshore sea ice and tidal glacier fronts in Svalbard poses risks for all three species, and will likely impact their distribution and survival negatively.

UiT The Arctic University of Norway
Faculty of Biosciences, Fisheries and Economics
Department of Arctic and Marine Biology

Joint supervision with the Norwegian Polar Institute

4 November 2017

Morten Heide

The influence of product, contextual and individual characteristics on food evaluation

The overall objective of this thesis is to provide insights with regard to how characteristics of the product, the context and the individual relate to consumer evaluation of food products. This thesis considered evaluation of food as a global attitude and as an evaluation of various attributes as expectations or experiences, and explore how evaluation is influenced by product, contextual and individual characteristics. This thesis contributes to the understanding of how food preparation or co-production influences evaluation. Satisfaction with co-production is an important determinant in the evaluation of a food product. This

factor could thus be used to gain better insights into how consumers perceive different products and the co-production involved in these products. The findings can be used by industry, retailers or other relevant stakeholders to develop products and marketing strategies.

Link to the thesis: https://munin.uit.no/handle/10037/11680

UiT The Arctic University of Norway
Faculty of Biosciences, Fisheries and Economics
Tromsø University Business School

13 January 2017

Astrid Marie Holand

Hvordan nød og nye ideer skaper nye lover: Speilvendingen av sjøgrenseloven i 1992

[How necessity and new ideas generate new laws: Revision of fisheries legislation in 1992]

The thesis demonstrates how legislation reflects society's changing needs and worldviews. The case is a legislative revision in the early 1990s, concerning fisheries. Until 1992 landings of fish catches from foreign vessels in Norwegian harbours was prohibited. When Northeast Arctic cod in the late 1980s became less abundant, the legitimacy of this legislation was questioned. This is a story of adaptive capacity in coastal communities, and of agents of change, who worked actively to change legislation and thus access resources in a new way. A central finding is that top-down- and bottom-up processes worked together to change the law, and allow for foreign landings. In this thesis, I draw on theories from innovation and resilience studies, both rooted in Schumpeter's ideas of creative destruction. I find that Norwegian fisheries policy used to be anchored in social concerns, but during the past 30 years, environmental concerns and market concerns have become dominating.

Link to the thesis: https://munin.uit.no/handle/10037/10099

UiT The Arctic University of Norway
Faculty of Biosciences, Fisheries and Economics
The Norwegian College of Fishery Science

21 June 2017

Mary Katherine Jones

Perceptions, Persuasion and Power. The textual shaping of Spitsbergen (Svalbard), 1895-1920: an international view

Scientific texts relating to Spitsbergen (Svalbard) published between 1895 and 1920, during the final quarter-century before Norway obtained sovereignty, relate their authors' scientific findings, but in many instances the texts' very existence, language and country of publication, and their authors' nationality also illustrate their historical and geopolitical significance, both as individual texts and as a cumulative literary canon. This thesis examines the textual shaping of Spitsbergen, in terms of which texts were published and what they were intended to portray. This bibliometric approach to history has uncovered interesting patterns of publication previously unsuspected. This new historiographical approach might be a means to (re)examine historical, political and cultural perspectives on the region.

Link to the thesis: https://munin.uit.no/handle/10037/11431

UiT The Arctic University of Norway
Faculty of Humanities, Social Sciences and Education
Department of History and Religious Studies

8 June 2017

Lars-Henrik Larsen

"Navigare necesse est". Bio Environmental implications of shipping in the European Arctic

With increasing global temperatures, the arctic ice cap is reduced in thickness and extent, making arctic shipping more feasible. The thesis looks into the biological and environmental implications of shipping in the European Arctic Seas. A scenario involving a shipping accident where a merchant vessel running on marine diesel oil is wrecked, provides the input to modelling of the spread of contaminants through a shallow-water arctic marine ecosystem. Data measured at an actual spill of diesel in the Arctic are also applied. Shipping in a future warmer Arctic is projected to include navigation during polar night, a period poorly

covered by biological data. The study's data on polar night fish feeding activity in the waters off Svalbard, indicate high biological activity and potentially similar ecosystem vulnerability during polar night and the light months.

Link to the thesis: https://munin.uit.no/handle/10037/11079

UiT The Arctic University of Norway
Faculty of Biosciences, Fisheries and Economics
Department of Arctic and Marine Biology

21 April 2017

Tan Thi Nguyen

Microbial community variation in an Arctic shelf seafloor. Biogeographic and anthropogenic influences

This thesis used next generation sequencing approaches to assess how microbial communities were distributed in an Arctic shelf seafloor across geographic separation and anthropogenic impact. As expected, higher taxa composition was stable across geographical distances, due to moderate spatial environmental variations. However, both bacterial and archaeal communities in the Barents Sea seafloor decayed over distance. Beta-diversity analyses of prokaryotes and viruses showed some degree of community structuring in accordance with the south-north spatial separation. While archaeal communities appeared largely influenced by environmental factors, the structure of bacterial communities seemed equally affected by environmental and spatial factors. Drilling waste discharges had observable effects on bacterial composition over a 100 m radius around the well.

Link to the thesis: https://munin.uit.no/handle/10037/10950

UiT The Arctic University of Norway
Faculty of Biosciences, Fisheries and Economics
The Norwegian College of Fishery Science

12 May 2017

Stian Olsen

Mechanisms of Host Plant Infection by the Parasitic Angiosperm *Cuscuta*

The highly adapted parasitic plants of the genus *Cuscuta* infect other plants to steal their water and nutrients. They develop specialized organs called haustoria that grow into the tissue of the host plant, establishing connections through which the parasite feeds. This thesis investigated the process of infection from multiple angles to shed light on the mechanisms underlying host tissue penetration by the *Cuscuta* haustorium. Analysis of cell wall compositions and wall-localized enzyme activities in host and parasite revealed that the walls of both plants are changed during infection, and indicated that specific host cell wall constituents could provide resistance against *Cuscuta*. This work has increased our understanding of *Cuscuta* parasitization and will assist development of new strategies to combat parasitic plants in agricultural areas.

Link to the thesis: https://munin.uit.no/handle/10037/10958

UiT The Arctic University of Norway
Faculty of Biosciences, Fisheries and Economics
Department of Arctic and Marine Biology

16 March 2017

Achim Randelhoff

Vertical nitrate fluxes in the Arctic Ocean

Upward mixing of remineralized nutrients is essential for photosynthesis in the upper ocean. Quantitative estimates of vertical nutrient supply were required to understand its role in the ecology and carbon cycle of the Arctic Ocean. To estimate the vertical flux of nitrate into the surface layer in contrasting hydrographic and dynamic regimes, profiles of turbulent microstructure and nitrate concentrations were measured from ships and ice camps from eastern Fram Strait into the Nansen Basin. These were supplemented with observations of the seasonal nutrient cycle in the same area, and reanalysis of available data on nitrate concentrations and turbulent mixing in other parts of the central Arctic Ocean. Hydrography was found to be the biggest

driver of variability in nitrate fluxes. Strong stratification restricted nitrate supply. Only the weakly stratified water in the Nansen Basin appears to have potential to support increased new production under a seasonal ice cover.

Link to the thesis: https://munin.uit.no/handle/10037/10948

UiT The Arctic University of Norway
Faculty of Science and Technology
Department of Physics and Technology

Joint supervision with the Norwegian Polar Institute

19 May 2017

Espen Mikal Robertsen

META-pipe – Distributed Pipeline Analysis of Marine Metagenomic Sequence Data

Recent advances in sequencing technology have led to huge progress in metagenomics. This thesis introduces the metagenomic analysis pipeline "META-pipe". With this tool, we supply a public analysis resource tailored to the marine domain, with an emphasis on analysis of full-length genes. META-pipe offers pre-processing, assembly, taxonomic classification and functional analysis of metagenomic sequence data. The pipeline has gone through several iterations, both in terms of functionality and implementation. This dissertation gives an overview of common strategies for metagenomic analysis in a pipeline context. It discusses the development of META-pipe through refinement and presents the current version.

Link to the thesis: https://munin.uit.no/handle/10037/11180

UiT The Arctic University of Norway
Faculty of Science and Technology
Department of Chemistry

1 June 2017

Alejandro Salgado Flores

Gut metagenomics in relation to diet and methanogenesis in arctic herbivores

This project characterizes the gut microbiome from reindeer (*Rangifer tarandus tarandus*), muskox (*Ovibos moschatus*), and rock ptarmigan (*Lagopus muta*), with emphasis on CH_4 metabolism and diets high in toxic plant secondary metabolites (PSMs). Investigating the microbiology of methanogenesis helps us understand the herbivores' digestive physiology. The first molecular study of gut microbiota of muskoxen and rock ptarmigans is presented. Reindeer fed lichens (high in PSMs) and muskoxen feeding on autumn pasture had increased proportions of methanogens. Muskoxen possess fiber-degrading bacteria, which allow them to live off fibrous plants like graminoids. Rock ptarmigans had a diverse microbiota with bacteria involved in degradation of PSM and polysaccharides. Both herbivores' gut microbiota would allow them to utilize the available food.

Link to the thesis: https://munin.uit.no/handle/10037/11080

UiT The Arctic University of Norway
Faculty of Biosciences, Fisheries and Economics
Department of Arctic and Marine Biology

20 November 2017

Eirik Mikal Samuelsen

Prediction of ship icing in Arctic waters – Observations and modelling for application in operational weather forecasting

Icing is a well-known threat to ships operating in a cold marine climate. This study used data from direct observations recorded on Norwegian Coast Guard vessels to develop a completely new icing model. This Marine Icing model for the Norwegian COast Guard (MINCOG) is more accurate than current methods for operational weather forecasting. The study stresses the importance of including wave information separately into marine-icing models rather than incorporating it in the wind-speed parameter. Nature dictates an upper limit to icing, since high waves and very low air

temperatures rarely coexist. Prediction methods that use the temperature at 850 hPa enable icing forecasts days or weeks ahead. If incorporated into an ensemble prediction system, these models may provide mariners early warning about the risk of icing.

Link to the thesis: https://munin.uit.no/handle/10037/11801

UiT The Arctic University of Norway
Faculty of Science and Technology
Department of Engineering and Safety

5 May 2017

Adriana Eva Sulvaran Sardi

Biomonitoring and risk assessment tools to manage impact of diesel oil in tropical coastal habitats

This work develops biology–based tools for environmental monitoring and risk assessment associated with diesel oil contamination in tropical coastal habitats. The general objectives are to validate use of antioxidant biomarkers as tools for biomonitoring coastal estuarine habitats in Brazil, and to compare the sensitivity and risk assessment metrics from species distributed from subtropical, temperate and Arctic regions exposed to a toxic PAH. Our results suggest that the sensitivities of species from Arctic and temperate regions are insufficiently similar to those from subtropical regions to allow comparison. We suggest that the search for metrics to safeguard the marine ecosystem should look beyond concentration thresholds. Such thresholds might be an inaccurate metric for species sensitivity, underestimating the risk to marine and estuarine ecosystems.

Link to the thesis: https://munin.uit.no/handle/10037/11169

UiT The Arctic University of Norway
Faculty of Science and Technology
Department of Engineering and Safety

12 May 2017

Åsmund Skjæveland

Energy inputs and upflow motion in the cusp

This thesis examines mechanistic details of how the energy in dayside aurora affects the upper atmosphere. Current models of the polar atmosphere are too coarse to simulate small-scale phenomena such as dayside aurora over Svalbard, and often underestimate the strength of these processes. The study shows that dayside aurora generates large amounts of heat, warming the atmosphere and creating vertical winds. Electrically charged gas in the upper atmosphere can rise hundreds of kilometres; neutral gas rises less, but in larger amounts. Together they stir the atmosphere dramatically and can disturb low-orbiting satellites. Charged gasses, including oxygen, can rise so high they are lost to space. The new knowledge in this thesis will contribute to proper modelling and better prediction of ionospheric activity.

University of Oslo
Faculty of Mathematics and Natural Sciences
Department of Physics

Joint supervision with the Department of Arctic Geophysics, University Centre in Svalbard

3 July 2017

Alexandros Tasianas

Fluid flow at the Snøhvit field, SW Barents Sea: process, driving mechanisms and multi-phase modelling

This PhD project was part of a large interdisciplinary EU project to understand the short- and long-term impacts of CO_2 storage on marine ecosystems. The thesis work focused on the Snøhvit hydrocarbon field and CO_2 storage site in the SW Barents Sea. The work was mainly based on interpretation of conventional 3D and high-resolution P-Cable 3D seismic data that were used to better understand deep-to-shallow fluid flow. Fluid flow was widespread in the Barents Sea. The observed features can be interpreted as gas chimneys, leakage along faults and fractures and other related features. Although fluid migration has taken

place in the past in the study area, we showed no active seepage of gas in the Snøhvit area.

Link to the thesis: https://munin.uit.no/handle/10037/11494

UiT The Arctic University of Norway
Faculty of Science and Technology
Department of Geology

28 April 2017

Balmukund S. Thakkar

A Biofocussed Chemoprospecting Approach to Drug Discovery: Design, Synthesis and Bioactivity Screening of Diverse Biofocussed Chemical Libraries

This thesis describes "biofocussed chemoprospecting". The essence of this new approach is to use diverse, yet "bio-like" compounds for efficient hit-finding, along with property filtering and optimization of qualities such as diversity of physicochemical properties, drug likeness, ease of synthesis and low cost for efficient selection of compounds. Three libraries based on biomolecules such as linear and cyclic dipeptides, and tartaric acid were designed. Virtual libraries were generated, and their physicochemical properties and drug likeness were analysed. The libraries of compounds with optimum diversity were synthesized, and multiple compounds with significant bioactivities were found. The overall success of the approach can be attributed essentially to the efficient library design as an outcome of focus on bio-likeness and optimized diversity – the core ideas of the biofocussed chemoprospecting approach.

Link to the thesis: https://munin.uit.no/handle/10037/11155

UiT The Arctic University of Norway
Faculty of Science and Technology
Department of Chemistry

10 November 2017

Marte Renate Thomassen

Occupational exposure, respiratory health and sensitisation among crab processing workers. A study among processors of king crab (*Paralithodes camtschaticus*) and edible crab (*Cancer pagurus*) in Norwegian land based crab processing plants

Occupational asthma and allergy are health problems in the seafood processing industry. This thesis investigated crab processing workers' exposure to central components in bioaerosols collected in their breathing zone, and the prevalence of respiratory symptoms and sensitisation to crustacean allergens. Both king crab and edible crab processing workers are exposed to bioaerosols containing these components. King crab processing results in higher levels of endotoxin, while edible crab processing yields higher levels of tropomyosin and total protein. Local differences in production, ventilation and plant layout are important for the exposure to bioaerosols. The prevalence of respiratory symptoms is higher among crab processing workers than non-exposed controls.

Link to the thesis: https://munin.uit.no/handle/10037/11742

UiT The Arctic University of Norway
Faculty of Health Sciences
Department of Community Medicine

22 June 2017

Ireen Vieweg

Biological effects of dietary crude oil on polar cod (*Boreogadus saida*)

Increasing human activities in the Arctic pose risks for accidental oil spills, but our knowledge of ecotoxicological effects on arctic organisms is still limited. This thesis investigated the effect of dietary crude oil exposure on lipid homeostasis, reproduction, and the antioxidant defence system of adult polar cod. Crude oil affected lipid homeostasis and metabolism, but generally adult polar cod appear to be relatively robust to low levels of dietary crude oil as no clear alterations were found in reproduction, gonadal maturation or the antioxidant defence system.

UiT The Arctic University of Norway
Faculty of Biosciences, Fisheries and Economics
Department of Arctic and Marine Biology

Joint supervision with the Norwegian Polar Institute

12 January 2017

Renat Yulmetov

Observations and Numerical Simulations of Icebergs in Broken Ice

Collisions with icebergs may significantly damage ships and offshore structures, threatening human lives and the environment. Preventing collisions requires ice management: icebergs must be detected and their drift forecast. This thesis analysed the drift of icebergs in broken sea ice and investigated the possibility of iceberg towing in sea ice to protect offshore structures. Icebergs and ice floes north-east of Greenland and south-east of Svalbard were GPS-tagged and their drift tracks were analysed to find drift velocities, trajectory curvatures, velocity spectra and to estimate relative drift of ice and icebergs. A numerical model of iceberg towing in broken ice was developed, which can efficiently simulate an iceberg moving through an ice field containing thousands of ice floes. The model was validated in basin-scale towing experiments. Based on the simulations, it appears feasible to tow a medium-sized iceberg in first-year ice up to concentrations of 70%.

Norwegian University of Science and Technology

Joint supervision with the Department of Arctic Technology, University Centre in Svalbard

Contact information

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

Fram Centre AS
Ph: +47 7775 02 00

Fram Institutions at the Fram Centre building
Visiting address: Hjalmar Johansens gate 14
Postal address: POB 6606 Langnes
N-9296 Tromsø
Ph: +47 7775 0200
Web: www.framsenteret.no

Akvaplan-niva AS
Ph: +47 7775 0300
www.akvaplan.niva.no

Geological Survey of Norway
Ph: +47 7775 0125
www.ngu.no

Institute of Marine Research Tromsø
Ph: +47 5523 8500
www.imr.no

Norwegian Coastal Administration
Ph: 07 847
International calls: +47 3303 4308
www.kystverket.no

NILU – Norwegian Institute for Air Research
Ph: +47 6389 8000
www.nilu.no

Norwegian Institute for Cultural Heritage Research
Ph: +47 7775 0400
niku.no

Norwegian Institute for Nature Research
Ph: +47 7775 0400
nina.no

Norwegian Mapping Authority Tromsø
Ph: 08 700
International calls: +47 3211 8121
www.statkart.no

Norwegian Polar Institute
Ph: +47 7775 0500
www.npolar.no

Norwegian Radiation Protection Authority
Ph: +47 7775 0170
www.nrpa.no

FRAM institutions elsewhere

CICERO – Center for International Climate and Environmental Research
Ph: +47 2285 8750
www.cicero.uio.no

NOFIMA
Muninbakken 9-13 Breivika
POB 6122, N-9291 Tromsø
Ph: +47 7762 9000
www.nofima.no

NIBIO
Norwegian Institute of Bioeconomy Research
POB 2284 Tromsø postterminal
N-9269 Tromsø
Ph: 03 246
International calls: +47 4060 4100
www.nibio.no

NORUT Northern Research Institute
www.norut.no

NORUT Tromsø
POB 6434 Forskningsparken, N-9294 Tromsø
Ph: +47 7762 9400
Fax: +47 7762 9401
www.norut.no/tromso

Norwegian Meteorological Institute
Main office: Henrik Mohns plass 1
N-0310 Oslo
Forecasting Division of Northern Norway
Kirkegårdsveien 60, N-9293 Tromsø
Ph: +47 7762 1300
met.no

Norwegian School of Veterinary Science
Dept. of Arctic Veterinary Medicine
Stakkevollveien 23, N-9010 Tromsø
Ph: +47 7766 5400
www.veths.no

Norwegian Veterinary Institute
Stakkevollveien 23, N-9010 Tromsø
Ph: +47 7761 9230
www.vetinst.no

NMBU
Norwegian University of Life Sciences
POB 5003, N-1432 Ås
Ph: +47 6723 0000
www.nmbu.no

SINTEF Nord AS
POB 118, N-9252 Tromsø
Ph: +47 7359 3000
www.sintef.no

University Centre in Svalbard (UNIS)
POB 156, N-9171 Longyearbyen
Ph: +47 7902 3300
www.unis.no

UiT The Arctic University of Norway
N-9037 Tromsø
Ph: +47 7764 4000
uit.no

Other institutions at the Fram Centre

Arctic Council Secretariat
Ph: +47 7775 0140
arctic-council.org

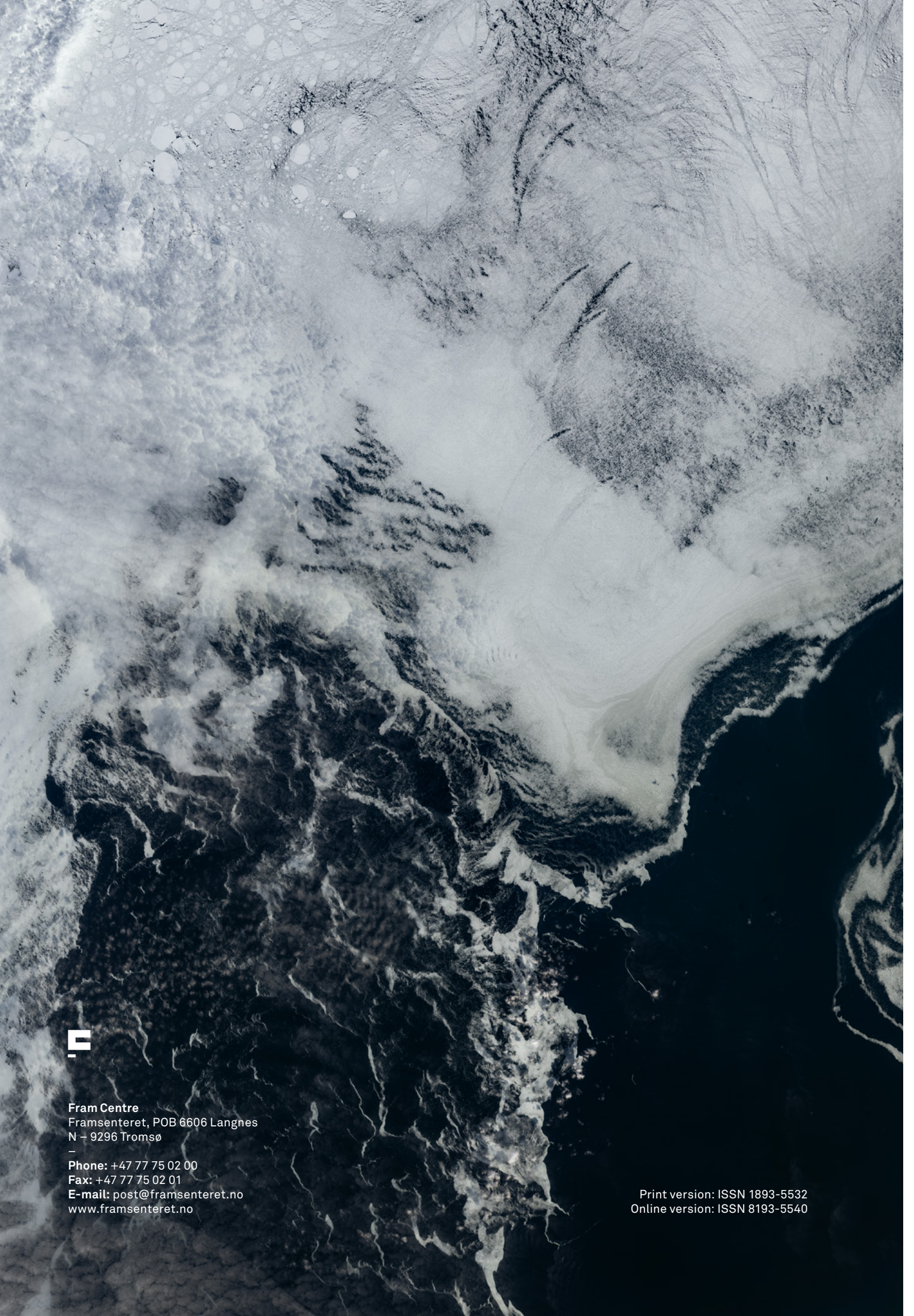
AMAP
Arctic Monitoring and Assessment Programme
www.amap.no

BarentsWatch
Phone: 07 847
International calls: +47 3303 4808
www.barentswatch.no

CliC International Project Office
Ph: +47 7775 0150
www.climate-cryosphere.org

International Centre for Reindeer Husbandry
www.reindeerherding.org

Polaria Visitors' Centre
Hjalmar Johansens gate 12, N-9296 Tromsø
Ph: +47 7775 0100
www.polaria.no



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
www.framsenteret.no

Print version: ISSN 1893-5532
Online version: ISSN 8193-5540