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Fram Forum

FRAM – High North Research Centre for Climate and the Environment

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2026

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Prepare for a cold spell in the Arctic

Since the end of the Second World War, western Europe has enjoyed peace and prosperity. Life here has felt predictable. The strategic alliances that took shape after the War endured. Our international agreements were largely respected. Free trade allowed small countries like Norway to specialise, building on their strengths while relying on others for goods and services they could not produce themselves. This was the world in which the Fram Centre was conceived, grew, and thrived.

Such confidence now feels as though it belongs to another era.

Many democracies have shifted toward autocracy in recent years, with authoritarians on every continent but Antarctica strengthening their influence. Every week brings new outrages: drones and missiles pummel civilian homes and infrastructure in Ukraine; power struggles in Gaza and South Sudan drive millions of people from one refugee camp to another; thousands of protesters are killed in Iran; poorly trained paramilitary forces are deployed to American cities in search of people who can be expelled from the country to meet an arbitrary deportation quota. No wonder the evening news leaves us feeling overwhelmed.

What does a changing world order mean for the Fram Centre?

For years, the Arctic has been remarkably free from geopolitical tensions. Arctic research, environmental protection, and emergency preparedness were coordinated among the circumpolar nations, largely thanks to the efforts of the Arctic Council. Now, however, two post-war ideals—territorial sovereignty and peaceful settlement of disputes through negotiation—are being rejected in favour of brute force. And Greenland lies squarely at the cross-section of those two ideals. The president of the United States argues that his country "need[s] Greenland for national security and international security" and "will go as far as we have to go" to get it. If the High North becomes a region of conflict and restrictions rather than cooperation and openness, it will be considerably more difficult for Fram Centre institutes to conduct research there.

Nor is this the only potential threat. Environmental research suffered when Russia was isolated after its invasion of Ukraine; Western scientists effectively lost access to data from half of the Arctic. Now other important sources of data are at risk because environmental research in the United States is being hamstrung.

American research organisations such as NASA and the National Oceanic and Atmospheric Administration provide data that are crucial to global environmental monitoring. But the current agenda in Washington calls for environmental research to be defunded, projects cancelled, and scientists fired. Several US websites that summarised and presented research findings in readily accessible form have been taken offline, and there is growing fear that decades worth of painstakingly collected data may be deleted from databases. In view of this threat, researchers at the Fram Centre and other organisations in Europe are downloading data potentially at risk, and archiving them in databases outside US control.

In addition to safeguarding historic data, European research institutes would be wise to cultivate collaborative networks, both between

and within countries, to increase their own research capacity. The European Space Agency is one obvious platform, already used to support remote sensing. Major EU grants could help ensure predictable funding. Arctic research entities could approach their counterparts in other nations with interests in the Arctic, actively searching for common ground on which to build specific research programmes. This will not be easy, but may be necessary.

So far, the Fram Centre collaboration remains strong, as is clear from this issue of Fram Forum. And we already implement some of the strategies sketched above. See for example the article about the International Kongsfjorden Year (p 76), which gathered research talent from fifteen institutes in seven countries. Another example is the recently launched Arctic Ocean 2050 project (p 160), which will be carried out by a broad consortium of eighteen Norwegian research institutes and universities.

In an unpredictable world, small players must adapt to survive. We need to keep all options open. We need innovation. And we need diversity– diversity of thought, of skills, of supply chains, and of relationships.

Clearly, we face a period of uncertainty and international volatility. But one thing is certain: the Fram Centre intends to remain a beacon for accessible, trustworthy science in the High North.

Janet Holmén, *Editor*

Publisher
Framsenteret Drift AS on behalf of
FRAM—High North Research Centre
for Climate and the Environment

Editor
Janet Holmén
Freelance editor
// janet.holmen@gmail.com

Executive
Helge M Markusson
Outreach coordinator
Fram Centre
// helge.markusson@framsenteret.no

Editorial committee

Ellen Kathrine Bludd
UiT – The Arctic University of Norway
// ellen.kathrine.bludd@uit.no

Trude Borch
Akvaplan-niva
// trude.borch@akvaplan.niva.no

Morten Günther
Norwegian Institute of Bioeconomy Research
// morten.gunther@nibio.no

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

Bente Kristin Rundereim Kjøllesdal
Institute of Marine Research
// bente.kjoellesdal@hi.no

Christine F Solbakken
NILU
// christine.solbakken@nilu.no

Cover photo (digitally modified)
Malin Daase

Layout
Tank Design Tromsø AS
www.tank.no

Printer
Lundblad Media AS

Online version
www.framforum.com

Contact information
FRAM Forum
Framsenteret Drift AS
POB 6606 Stakkevollan, N-9296 Tromsø
NORWAY

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

The changing of the guard

The Ministry of Climate and Environment has appointed Kari Nygaard as chairperson of the Fram Centre's highest governing body, the Steering Committee of FRAM— High North Research Centre for Climate and the Environment. She takes over the role from Bo Andersen.

A FEW YEARS AS CHAIR OF THE FRAM CENTRE'S STEERING COMMITTEE

The strongest feeling I have after a little more than five years in this leadership role is gratitude for having had the opportunity to be part of it all. It has been a privilege to work with all the people, especially Helge M Markusson and Kathryn Donnelly in the Fram Centre secretariat, and the members of the Steering Committee during these years. In addition, the past few years have shown me the prodigious breadth of interdisciplinary expertise among the institutions and researchers involved in the collaboration.

But the most important question is whether we have achieved what the Fram Centre collaboration was aiming for. My understanding was that the ministry wanted to strengthen the interdisciplinarity and breadth of the collaboration and move it out of silos that the old flagship programmes were becoming. Subjectively speaking, I believe that the answer is at least partly yes. In particular, I have received a lot of positive feedback that interdisciplinarity, though at times imposed, has been extremely useful for most of the major programmes. The five-year major programmes have ensured long-term continuity, but may have limited flexibility.

Both the major programmes and the smaller projects have produced a great deal of good research. However, it remains to be seen whether the major programmes have been scientifically successful. The plan is to have them externally evaluated after they are completed. We must also acknowledge that these major programmes have demanded a great deal of organisation, which has at times been challenging. The scope of this work has been underestimated by me, the Steering Committee and the researchers themselves. The lessons we have learned will hopefully be put to use in future programmes.

I am pleased that the Fram Centre collaboration has established a well-functioning dissemination group under Helge's leadership, and that we now have a functional reference group, thanks to Kathryn's efforts.

The members of the Steering Committee have skilfully and adeptly formed an overview of the challenges. There have been very few votes in the Steering Committee; we have consistently tried to operate according to the principle of consensus. That means no one gets exactly what they want, but any dissatisfaction is evenly and acceptably distributed among the members of the group.

Perhaps our most hard-won achievement has been a significantly greater understanding that the research conducted by the collaboration must be relevant for environmental management. I feel that the researchers at the Fram Centre have largely embraced this idea. The collaboration should not be doing the kind of research that can be done in a project funded by open sources—it should be policy-driven.

With support from the Research Heads' Group, the Steering Committee is working through the first months of 2026 to prepare calls for new programmes and projects for the period starting in 2027. The work has begun, and I am convinced that the Steering Committee, under Kari Nygaard's leadership, will develop the current situation into something even better than what we have achieved during my tenure.

Thank you for these years, and thank you to the Ministry of Climate and Environment for their willingness to fund this collaboration.

Bo Andersen

EXCITING

My name is Kari Nygaard, and I have had the pleasure of serving on what was the highest governing body (the general assembly) of the Fram Centre for 12 years. I have a strong interest in the Arctic and the Fram Centre, and I have had the pleasure of participating both through NILU (and NIVA) and through board positions at the Norwegian Space Agency.

I have worked at several institutes, starting at the Institute of Marine Research in the late 1980s, and then moving to NIVA, where I earned a PhD in marine microbiology. After twenty years at NIVA, I moved to NILU, where I led the institute for 12 years. I now run my own company.

I have extensive experience serving on boards in academia, the Research Council of Norway, the Norwegian Space Agency and Kjeller Innovasjon. In addition, I have held several international board positions.

It will be exciting to lead the research work that is primarily funded by the Ministry of Climate and Environment. The Fram Centre is an important collaboration among 21 members with strong expertise in climate- and environment-related research. The work is extremely important for the management of the Arctic and requires close collaboration among researchers from the member institutions of the Fram Centre.

Kari Nygaard

GOVERNANCE STRUCTURE AT THE FRAM CENTRE

STEERING COMMITTEE

The steering committee provides strategic oversight and guidance to the research collaboration. The committee consists of the following members:

Leader: Kari Nygaard, appointed by the Ministry of Climate and Environment
Deputy: Evy Jørgensen, Norwegian Polar Institute

Members:
Jørgen Berge, UiT The Arctic University of Norway
Noortje Dijkstra Haugstvedt, Norwegian Mapping Authority
Rune Storvold, NORCE
Eirik Mikkelsen, Nofima
Alma Thuestad, Norwegian Institute for Cultural Heritage Research
Elina Haltunnen, Norwegian Institute for Nature Research

RESEARCH HEADS' GROUP

The research heads' group is the Fram Centre's principal cooperative body for research heads. The group consists of one appointed representative from each of the 20 member institutions that wish to participate, as well as the heads of the Flagship research programmes.

Leader: Alma Thuestad, Norwegian Institute for Cultural Heritage Research

OUTREACH GROUP

Appointed by the steering committee
Leader: Helge M Markusson, Fram Centre secretariat

Members:
Karine Nigar Aarskog, Norwegian Polar Institute
Randi Lillealtern, Norwegian Institute for Nature Research
Hanne Karde, UiT The Arctic University of Norway
Trude Borch, Akvaplan-niva
Katrine Jaklin, NORCE
Bente Kjøllesdal, Institute of Marine Research
Asbjørn Bartnes, Nofima

REFERENCE GROUP

Appointed by the steering committee
Leader: Kathryn Donnelly, Fram Centre secretariat

Members:
Marianne Kroglund, Norwegian Environment Agency
Gøril Voldnes, Directorate of Fisheries
Hilde Haug, Norwegian Food Safety Authority
Knut Aune Hoseth, Norwegian Water Resources and Energy Directorate
Stig-Morten Knutsen, Norwegian Offshore Directorate
Astrid Fjose, County Governor of Troms and Finnmark
Sten Olav Hætta, Sami Parliament
Bjørn-Rikart Pedersen, Finnmark Estate

FRAMSENTERET DRIFT AS

The company Framsenteret Drift AS is owned by a group of the Fram Centre's member institutions. Framsenteret Drift AS is responsible for operating the collective services in the Fram Centre building and hosts the secretariat designated for the Fram Centre collaboration.

CEO: Inger Christiansen

Bente Kjøllesdal // Institute of Marine Research

Troubleshooter in the fjord: bringing a barren ecosystem back to life

PROFILE

With the Porsanger Fjord as his office backdrop, the marine scientist Hans Kristian Strand conducts small experiments with major implications. “The common thread in everything I do – and our main reason for being here – is that we want the resources to return,” he says.

Strand runs the field station in Holmfjord, Finnmark, the northernmost outpost of the Institute of Marine Research. Right outside his office window lies Porsangerfjorden, the Arctic fjord he has worked in, on, and along for 15 years.

Before the Second World War, the fjord teemed with rich fisheries.

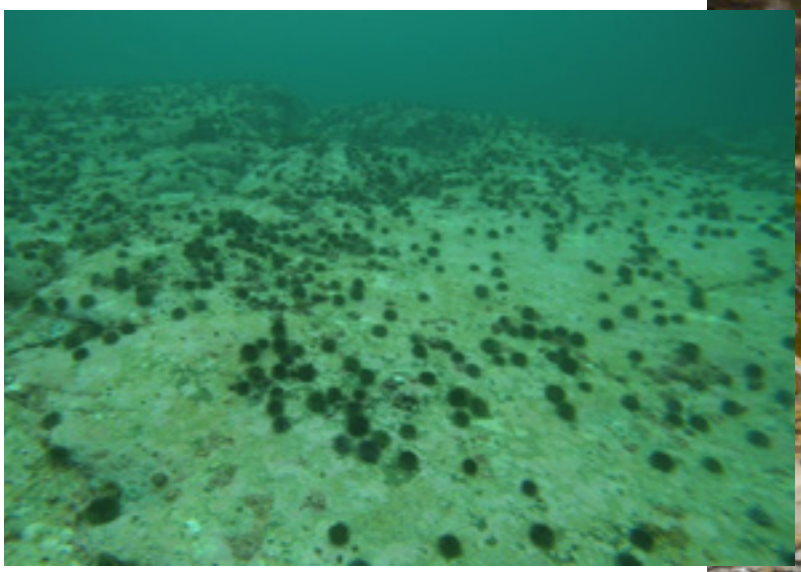
“But the fisheries have been absent for so long that people have grown used to it. Those who grow up here today have never experienced anything other than an empty fjord.”

A VICIOUS CIRCLE

The ecosystem in Porsangerfjorden has gone through major changes over many years: declining fish stocks, sea urchins grazing down the kelp forest, king crabs marching in.

Green sea urchins do not normally attack healthy kelp, but if they become abundant and hungry enough, they can graze down vast areas.

When key species like plaice, large haddock, and wolffish disappeared from the fjord, the mechanism that kept the voracious sea urchins in check disappeared as well. The kelp forest turned into a desert.



Hungry sea urchins transform kelp forests into barren wastelands, as here in Porsangerfjorden. *Photo: Institute of Marine Research*

Hans Kristian Strand.
Photo: Tor Even Mathisen / Institute of Marine Research

The field station in Holmfjord.
Photo: Tor Even Mathisen / Institute of Marine Research

"Once you've created a situation where sea urchins proliferate and graze down the kelp forest, it's not enough to simply stop fishing wolffish. Without the kelp forest as an important nursery habitat, it's difficult for fish to return," says Strand. "It becomes a vicious circle, where the ecosystem is suppressed."

And so the fjord has remained for decades.

But Strand is researching how these negative trends can be reversed—and his results show that there is hope on the horizon.

FISH AND FJORD

Hans Kristian Strand was born in Finnmark, but his family soon moved to the Nordland municipality of Fauske, where he grew up. He developed an early interest in the sea and in fish.

"One of the first things I did when I caught a fish was to gut it to see what it had eaten," he recalls.

As a student, his interests were many and wide-ranging. Among them was the aquaculture industry that had become established in Norway by the late 1980s. Strand was particularly fascinated by the prospect of farming new marine species.

With a master's thesis on halibut farming from the University of Bergen under his belt, Strand began gradually moving northward.

Nonetheless, fjord ecology would ultimately shape much of his research career.

THE GARAGE BAND FEELING

The northern field station has two full-time employees: Hans Kristian himself and his wife Mette—a duo both professionally and privately. They also have a reliable helper in Alf Børre Tangeraas.

"Working at a field station has some disadvantages; it's a small environment," says Strand.

But the network they have built in the north is large. They have long-standing and extensive cooperation with fishers, industry, and municipalities.

"And it wouldn't work without the support we receive from researchers, technicians, and administrative staff working elsewhere."

Strand admits that it's no coincidence he ended up in the north: "At a small field station you get to keep that close-knit garage band feeling; you can get quite a lot done without being bogged down in bureaucracy."

His workdays are divided between a boat on the fjord, the field station laboratory, and his office desk.

"To be here in this slightly chaotic zone where we can explore new concepts—and that this is actually our job—that is a privilege," he says.

YEARS OF EXPERIENCE

The northern field station of the Institute of Marine Research is located in a closed-down fish processing plant. It was this empty space full of potential that lured Strand and his wife back to Finnmark.

For several years, they ran their own business along the fjord, raising cod fry for sale.

At the same time, they collaborated with the municipality to investigate why coastal cod had disappeared from Porsangerfjorden. Their focus quickly turned to sea urchins.

"When conditions in the fjord meant that cod were no longer viable, we tried to reduce the sea urchin population by commercialising it," says Strand. "But the urchins contained little roe—and it's the roe that has monetary value. They had grazed down the kelp forest and thus their own basis for survival."

Hans Kristian Strand taking a coffee break with Alf Børre Tangeraas, jack-of-all-trades at the field station. *Photo: Institute of Marine Research*

Before the processing plant became a field station and part of the Institute of Marine Research in 2010, the Strands had amassed years of experience with the fjord's complex ecosystem challenges– and ideas about how to address them.

AN ECOLOGICAL CATASTROPHE

Kelp forests are key ecosystems along the coast. These blue forests produce oxygen, store carbon, and remove excess nutrients from the water. They are also nursery grounds and homes for a great diversity of species, from sponges, snails, and mussels to crabs and, of course, fish.

This is where fish hatch and grow. At night, predators enter from the deep to feed.

But human activity has put kelp forests in danger. Nearly 60% of the world's kelp forests are declining.

In northern Norway alone, around 5,000 square kilometres of kelp forest have been lost.

"The collapse of the kelp forest was an ecological catastrophe. But because it happened underwater, it received little attention. If this had happened on land, it would be all we talked about," says Strand. But awareness is beginning to shift.

Kelp forest restoration is now on the agenda, and the issue has appeared in opinion pieces, newspapers, radio programmes, and news broadcasts.

Private citizens, non-governmental organisations, and politicians are speaking out in favour of a rescue operation. In June 2024, the Norwegian parliament requested a plan to reverse the trend.

At the same time, Norway does cutting-edge research on kelp forests, some of it at a field station in Holmfjord.

IT ALL BEGAN AT FELLESKJØPET

At the field station, small experiments are carried out all the time. In 2013, marine researchers spread burnt lime in Porsangerfjorden for the first time to test whether lime could kill sea urchins.

“It all started when we went to Felleskjøpet, a supply store specialising in farming supplies, and bought 20 kilos of agricultural lime. We wanted to check whether water in Arctic areas was too cold for lime to be effective at all,” Strand explains.

When burnt lime is mixed with water, the alkalinity increases rapidly, causing a short-term corrosive effect. Echinoderms such as sea urchins are extremely vulnerable to this treatment, whereas shellfish, crabs, and fish are barely affected.

The researchers found their test site right outside the office window: swarms of sea urchins had settled around the pier by the field station.

“The sea urchins died, and the following year, the kelp grew.”

Their experiment was scaled up. The areas they treated with lime were already mostly barren– the sea urchins had created marine deserts.

For over a decade, the researchers monitored changes, and in Porsangerfjorden the results were striking: in lime-treated areas, lush kelp now grows. And the invasive king crab has taken over the role of wolffish, haddock, and plaice in keeping sea urchin numbers down.

Kelp forests were reestablished in places treated with burnt lime. This picture was taken in Porsangerfjorden in September 2024, a decade after lime treatment began.
Photo: Institute of Marine Research

JUVENILE FISH IN PERIL

Ecosystems are complex networks. If changes occur in one part, they can set off chain reactions.

When a top predator like cod disappears, its niche does not stand empty waiting for it to return– quite the opposite.

Species like sculpin, which sit mid-level in the food chain, seize the opportunity. Their numbers increase and they move into the available habitat.

“We’ve calculated that there are many millions of them in Porsangerfjorden, and we’ve documented that sculpin are voracious eaters with a great appetite for juvenile cod.”

The researchers hoped that if the kelp forest was restored, the juvenile fish would survive. They set up an experiment to test the hypothesis:

“We released juvenile cod and saithe in an aquarium experiment where predators like sculpin and small cod were present, and where seaweed and kelp provided plenty of hiding spots. We assumed this would protect the young fish.”

But they were wrong. The experimental setup put the juveniles in a perilous position.

“Small cod chased the juveniles down into the kelp forest, where they were eaten by sculpins. The juveniles that the sculpins missed darted upward, where they were swallowed by the small cod.”

In other words, restoring the kelp forest wasn’t enough. To recreate an ecosystem where coastal cod larvae could grow to adulthood, the researchers also needed to figure out how to ensure that the juveniles survived.

They needed another predator.

“We introduced a wolffish. It was very aggressive. Every time it saw a sculpin, it chased it away. The sculpins had all they could handle simply trying to hide: they posed less of a threat, and far more juvenile cod and saithe survived.”

Hans Kristian Strand is equally at home in a boat on the fjord as at his desk in the field station. And the collaborations are many: “We gain knowledge about the fjord that is completely unique,” says Strand. *Photo: Tor Even Mathisen / Institute of Marine Research*

MEANINGFUL DETOURS

Hardly a day passes without Strand heading out on the fjord he devotes much of his research to. The field station is right by the water, and the research boat lies ready at the pier.

“It’s not necessarily whatever it is we’re actually studying that’s most exciting, but all the side things that crop up while we’re out there, with our hands in the water,” he says.

“I’m not married to my research questions, and I appreciate being able to follow up on unexpected tangents.”

That was also the case with one of the latest innovations in the north.

We know that kelp forests are vital feeding and nursery grounds for juvenile fish, but sculpins know this too. The researchers realised that if they were to help the young fish survive, they needed to recreate kelp habitat beyond the sculpins’ reach.

“After quite a lot of trial and error, we suddenly stumbled on a concept that exceeded our expectations: artificial kelp reefs.”

Photo: Tor Even Mathisen / Institute of Marine Research

RECORD RESULTS

This past winter, the researchers lowered artificial reefs into Melkøysundet, a sound outside Hammerfest.

The reefs stand at about 20 metres depth and are anchored with a ring resting on the seabed. From this ring, ropes stretch 10 to 15 metres upward in the water column.

Four months later, research divers went down to inspect whether the reefs had borne fruit.

"They were covered in lush kelp, in record time. Kelp grew densely on all the reefs we had placed, and we saw both cod and saithe juveniles in large numbers around the structures," says Strand.

Between the reefs, the researchers have introduced a voracious rescue patrol: wolffish.
The wolffish became popular as food in the 1960s, but the population could not handle the consumer demand.

Now, Strand and his colleagues at the Institute of Marine Research have carried out an unusual relocation: twenty wolffish were caught along the coast and transported to their new home in Melkøysundet. If they thrive, the predator may curb the sea urchin problem and give the kelp forest the respite it needs.

"Then the wolffish can help break the negative spiral that keeps the ecosystem overgrazed."

FOOD AND TRADITIONS

A combination of different methods and approaches will likely be required to secure a thriving kelp forest, and eventually a re-established coastal cod stock.

"In the past, you could put the potatoes on to boil, then go out and bring back the fish you wanted for dinner. Without that access to fish, people wouldn't have lived here. The world changes–obviously it changes–but when that access is lost, we lose something more," says Strand.

It's not only about food resources and understanding the biological interplay in the fjord–it's also about cultural heritage.

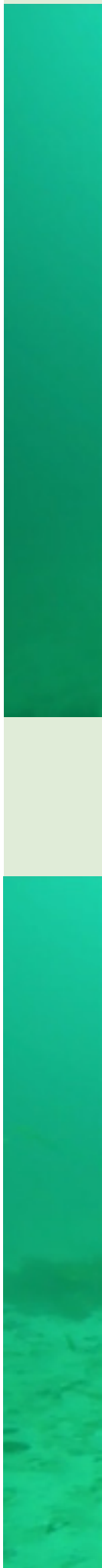
"Have you heard of *skaveltorsk*?" Strand asks. "Cod that were caught here late in autumn were buried in snowdrifts (*skavler*), and then eaten throughout the winter. They would be somewhat worse for wear when spring approached, but had a distinctive sour, fermented flavour. Skaveltorsk was eaten with seal blubber."

Sour cod (*surtorsk*), on the other hand, was cod packed in jute sacks early in the year and stored among the shoreline stones.

"It's a food culture almost no one has heard of. These are methods of preparing and preserving cod, and they're about surviving on the resources available."

Porsangerfjorden is still lacking the abundance of fish it used to have. But Hans Kristian Strand is optimistic about its future: "My fundamental belief is that we can pull this off–that the resources can return and become at least as productive as they once were. We just need to avoid making the same mistakes again." ■

"They were covered in lush kelp, in record time. Kelp grew densely on all the reefs we had placed, and we saw both cod and saithe juveniles in large numbers around the structures."



Kelp grows densely on the artificial reef (above) and large numbers of juvenile cod congregate near the reef's anchor ring (below).
Photos: Institute of Marine Research

Lise Loktu, Ionut Cristi Nicu and Alma Thuestad // Norwegian Institute for Cultural Heritage Research

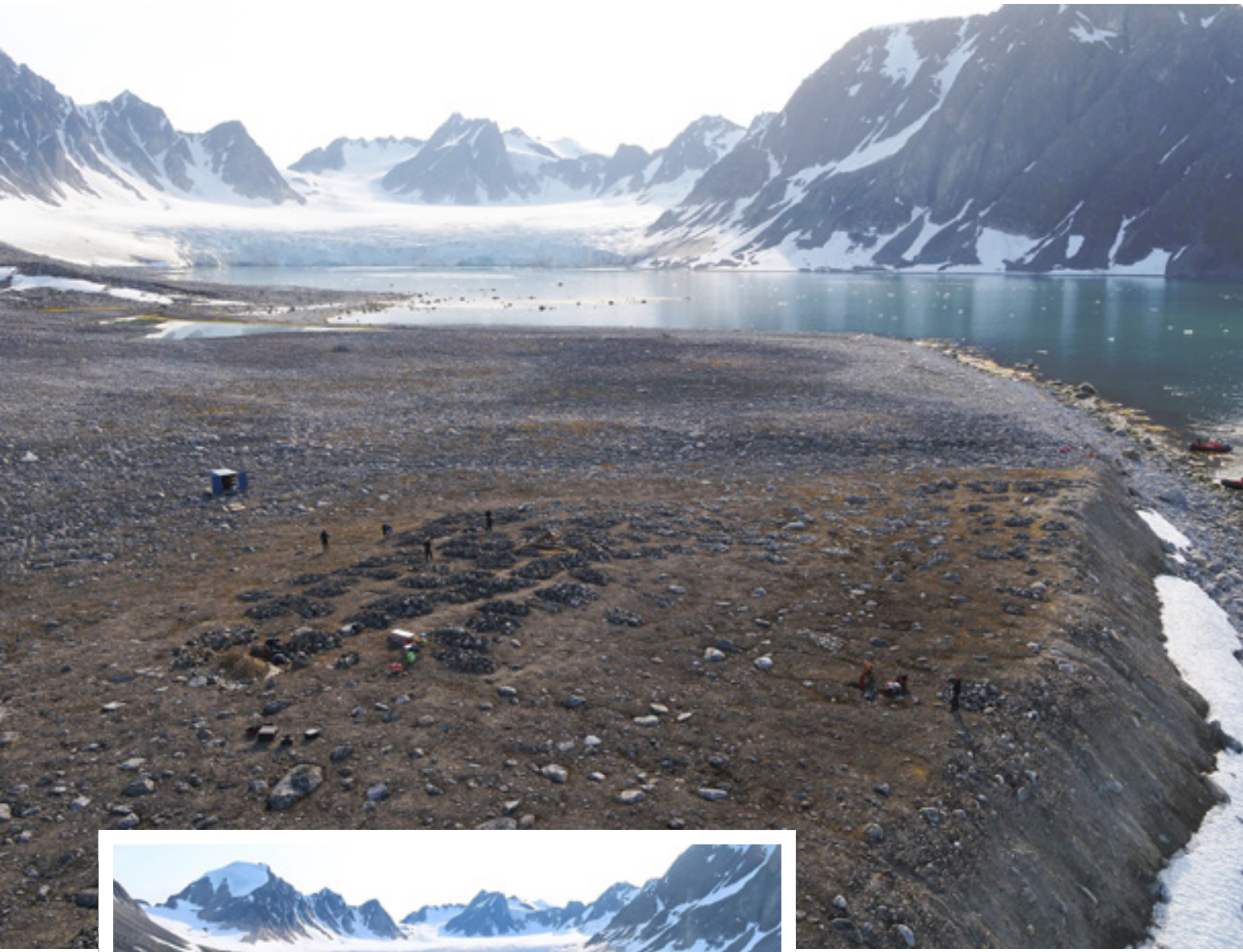
Cultural heritage under pressure from climate change and policy blind spots

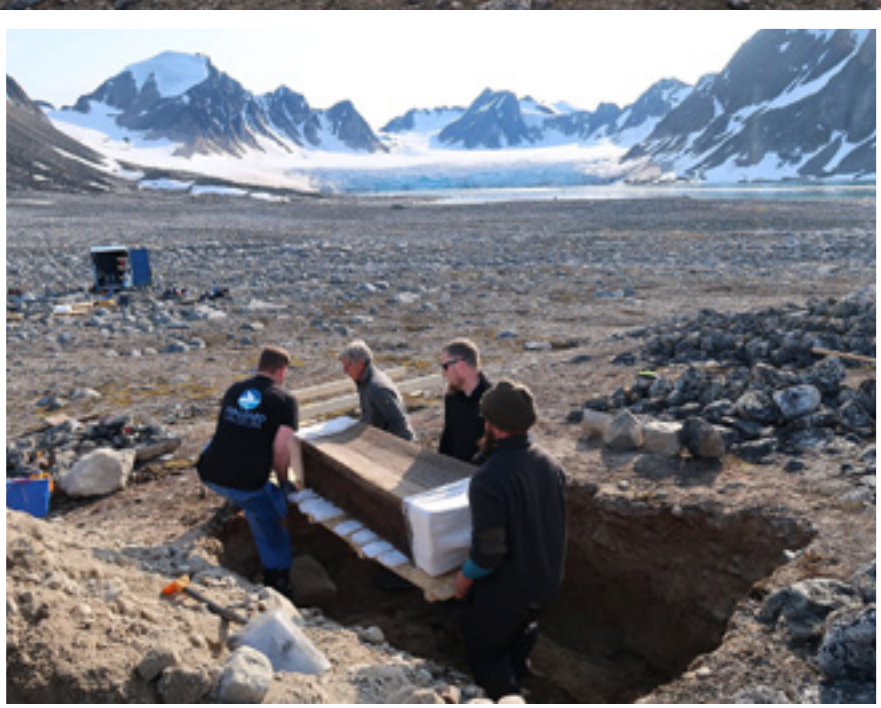
RESEARCH NOTES

Svalbard's cultural heritage is being lost as permafrost thaws and erosion accelerates. At the whalers' burial site Likneset, deeper active-layer thaw is increasing microbial activity and speeding up decay of organic remains. This shows the urgent need to integrate cultural heritage into Arctic climate strategies.

Svalbard's cultural heritage forms one of the most intact historical archives in the European High Arctic. Traces of whaling, trapping, scientific activity, mining, and military presence are distributed across the landscape, offering unique evidence of human adaptation and resource use over four centuries. These sites are now deteriorating at an accelerating pace. Permafrost thaw, coastal erosion, increased precipitation, and unstable ground are degrading organic materials and reshaping cultural landscapes. As these sites collapse or wash away, essential knowledge about long-term human-environment interactions is lost.

Although the environmental consequences of climate change are widely monitored and modelled, cultural heritage remains a blind spot in Svalbard's climate strategies. Unlike biodiversity or natural hazards, archaeological sites are not included in systematic monitoring systems, and no long-term datasets exist to quantify degradation or guide prioritisation. Heritage management is further constrained by limited staffing, fragmented documentation from earlier surveys, and funding structures that prioritise development-led archaeology in southern Norway.





The 17th-century whalers' burial site at Likneset in Smeerenburgfjorden is Svalbard's largest whaling burial site. The site is increasingly affected by coastal erosion and permafrost thaw. Recent excavations (2016/2019) reveal sharply worsened preservation compared to the 1980s: collapsed coffins, fragmented skeletal remains, and near-total loss of textiles. The site provides clear evidence of accelerating climate-driven degradation of Arctic heritage. *Photos: Lise Loktu / NIKU (© The governor of Svalbard, 2019)*

Human activity adds further pressure. Tourism continues to grow, and many visitors seek access to “last chance” Arctic landscapes. Sites such as Smeerenburg and Gravneset are among the most visited locations on Svalbard, despite being among the most sensitive. Foot traffic, soil compaction, vegetation loss, and demand for new infrastructure disproportionately affect fragile sites, while research and logistics leave additional footprints. The combined pressures of warming, natural erosion, and visitation threaten irreplaceable historical resources and weaken the evidence base needed for informed climate adaptation.

Cruise tourism at Smeerenburg (top) and Gravneset (bottom). These highly visited sites illustrate how human activity amplifies climate-driven pressures, contributing to erosion, vegetation loss, and cumulative degradation of Arctic archaeological environments. *Photos: Tommy Dahl Markussen*

LIKNESET: MEASURABLE CLIMATE IMPACT

The whalers' burial site at Likneset in Smeerenburgfjorden exemplifies several of these challenges and served as the starting point for the project CLIMARCH (RIS ID 12194), run by the Norwegian Institute for Cultural Heritage Research (NIKU). CLIMARCH aims to investigate how climate change drives the degradation of archaeological environments in Svalbard by using the whalers' burial sites in Smeerenburgfjorden as case studies. More than 700 graves are registered in the area, and about 100 were excavated in the 1980s, including 14 at Likneset. Several graves yielded exceptionally well-preserved textiles-some of the best-documented examples of 17th-century working garments worldwide.

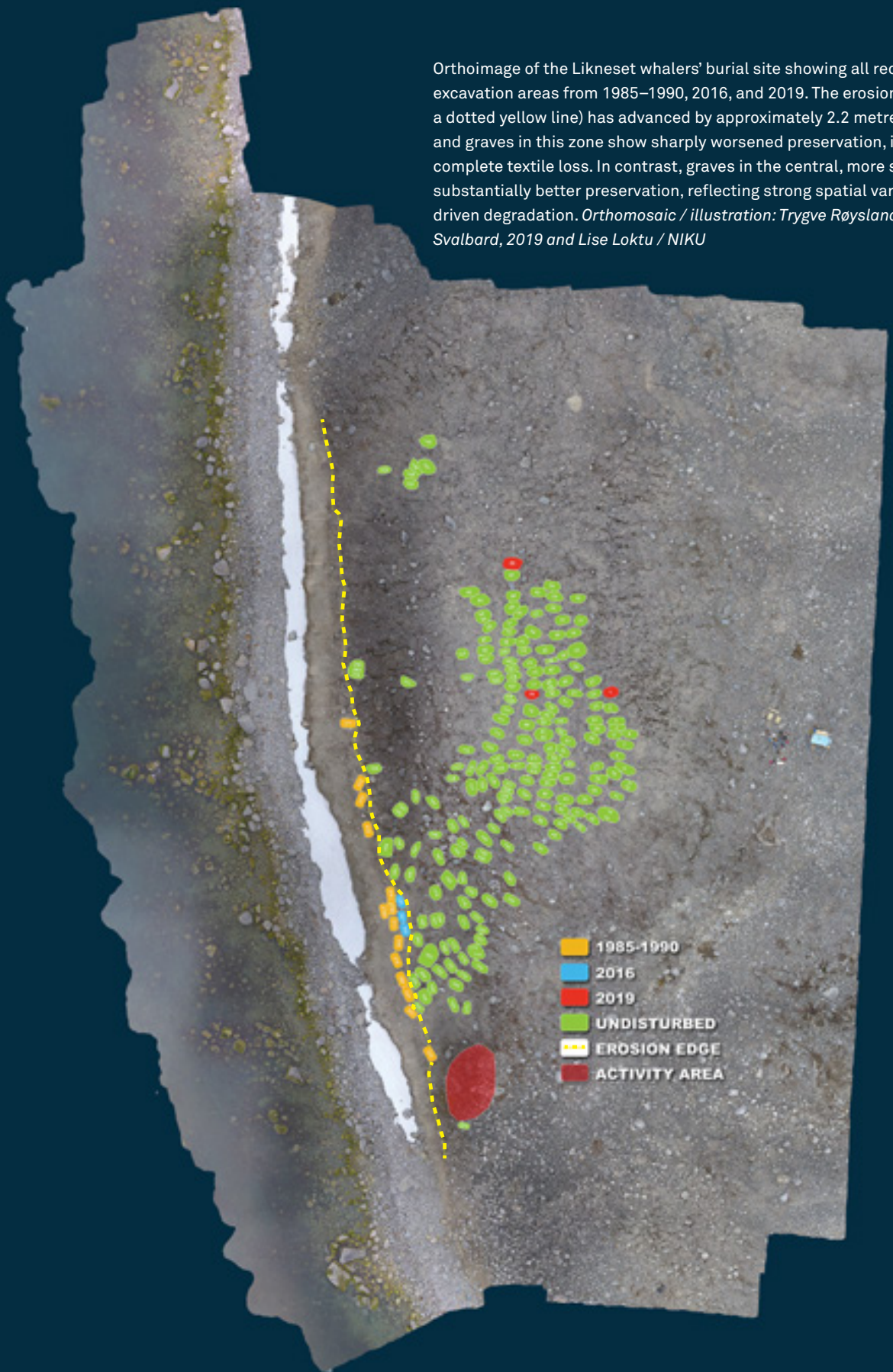
Since then, coastal erosion has caused continuous physical destruction at several sites, especially visible at Likneset. Although the erosion front has advanced only about 2.2 metres (2016) since the 1980s, burial structures and coffins have collapsed due to solifluction, fragmenting textiles and skeletal remains, while sediments and increased oxygen exposure have penetrated the burial fills. When new excavations were carried out at the Likneset site in 2016 and 2019, preservation conditions had worsened markedly. Comparable textile finds were almost entirely absent in erosion-prone areas, in sharp contrast to the 1980s material. This rapid loss likely reflects increased microbial activity and accelerated decay driven by deeper active-layer thaw, greater water infiltration, slope instability, and shoreline retreat.

Erosion-related damage to graves at Likneset, documented during the 1985 excavations. Graves in erosion-prone areas show clear signs of disturbance caused by subsurface instability, solifluction, and ground fissuring. Cairns and stone linings had shifted downslope, while coffins exhibited collapsed lids, warped panels, and displaced skeletal remains. Such disturbances created microenvironments that accelerated decomposition by allowing moisture, sediment, and oxygen to enter the burial. *Photos: Dag Nævestad / Tromsø Museum*

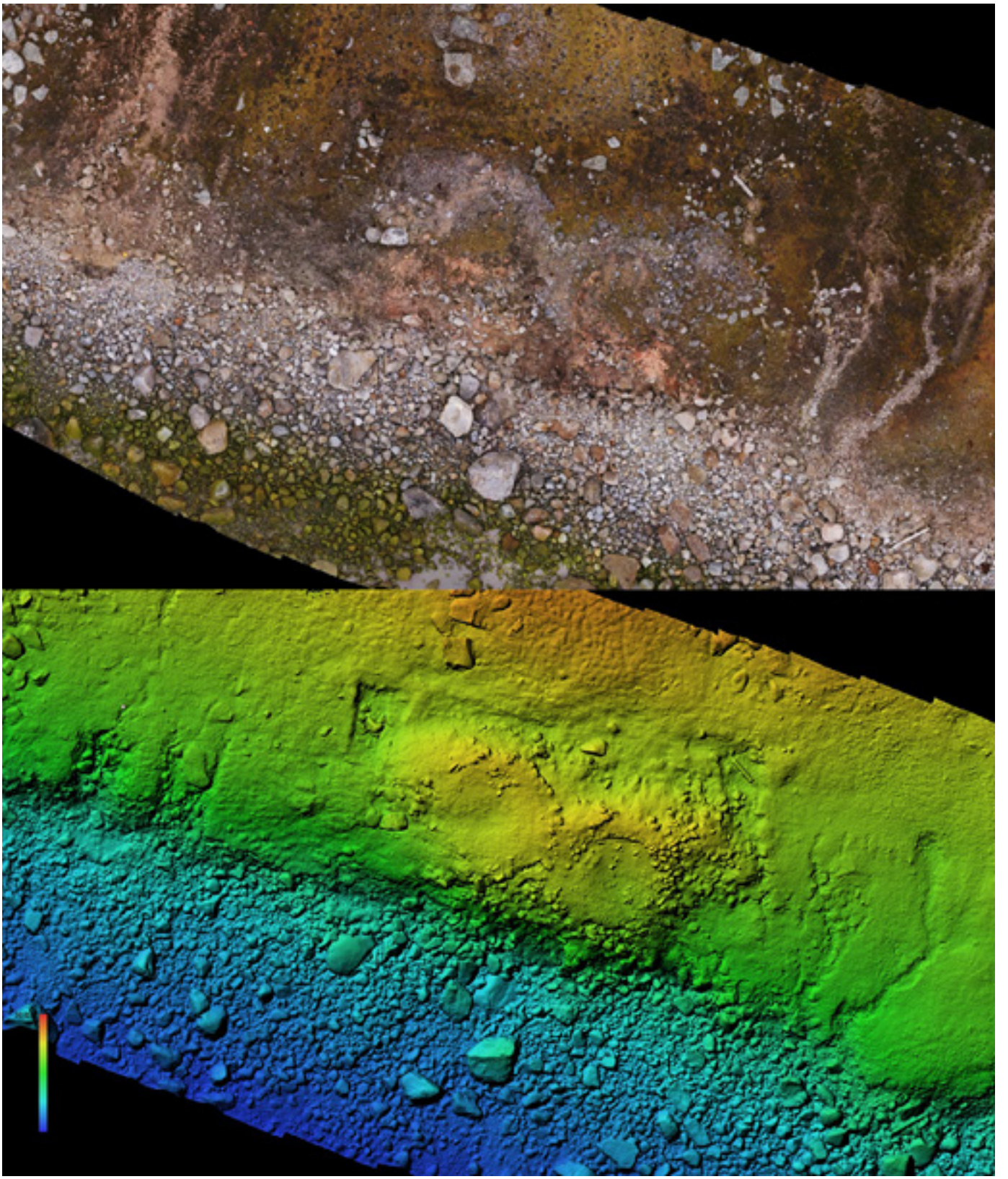
Comparative overview of textiles excavated at Likneset in 1985–1986 (1, top row), 2016 (2, bottom row), and 2019 (3, middle row). The figure illustrates variations in textile preservation across excavation periods. Garments from the erosion-prone area excavated in the 1980s (1) include well-preserved woolen jackets, breeches, and accessories, often with intact seams and buttons. Finds from 2016 (2), from the same area, are significantly more fragmentary, with very few textiles and extensive degradation. In contrast, textiles from the more stable central area excavated in 2019 (3) are much better preserved and closely resemble the 1980s material. *Photos: Lise Loktu / NIKU and Svalbard Museum*

The Likneset site has therefore served as a key pilot site within the CLIMARCH project. To systematically assess climate-change impacts, we applied a semi-quantitative preservation grading system linked to taphonomic change in archaeological materials (i.e. processes affecting remains after death). Using standardised criteria on coffins, textiles, and skeletal remains across three excavation phases makes it possible to compare conditions over more than three decades. When considered alongside drone-based orthophotos, regional geological context, erosion observations, permafrost studies, and climate records, the data indicate clear spatial patterns: the poorest preservation is associated with unstable sediments affected by cracking, subsidence, and erosion, while better-preserved graves are found in more stable inland areas.

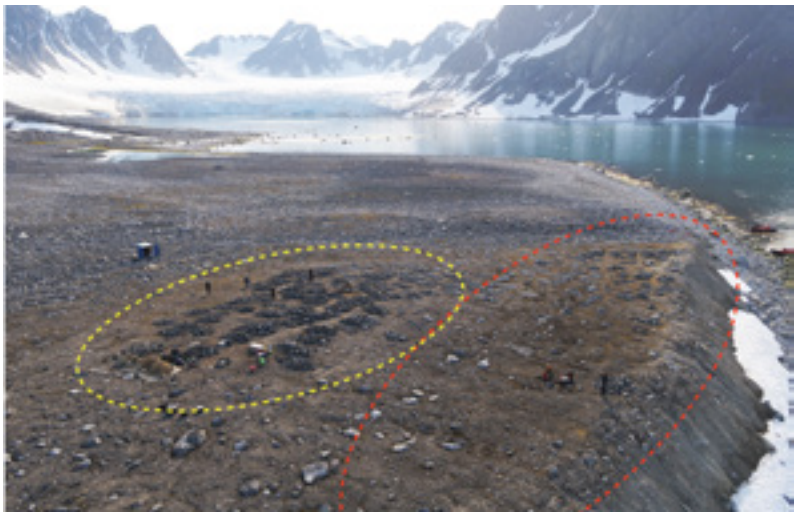
The Likneset case offers a practical model for climate-adaptive heritage management. Repeated grading using the same grading system at regular intervals could function as an early-warning tool for sites approaching critical thresholds. When combined with environmental datasets, including ground temperature, coastal processes, precipitation, sea-ice conditions, and wave exposure, this approach can help managers anticipate where loss is most likely to occur next and determine when emergency documentation or excavation is required.



Orthoimage of the Likneset whalers' burial site showing all recorded graves and excavation areas from 1985–1990, 2016, and 2019. The erosion front (marked with a dotted yellow line) has advanced by approximately 2.2 metres since the 1980s, and graves in this zone show sharply worsened preservation, including near-complete textile loss. In contrast, graves in the central, more stable area retain substantially better preservation, reflecting strong spatial variation in climate-driven degradation. *Orthomosaic / illustration: Trygve Røysland © The Governor of Svalbard, 2019 and Lise Loktu / NIKU*



UAV-based orthophoto (top) and digital elevation model (bottom) of blubber ovens at Ytre Norskøya, showing severe erosion and surface destabilisation. Remote sensing provides an efficient tool for monitoring vulnerable archaeological structures in Svalbard. Combined with permafrost data, coastal dynamics, climate records, sea-ice conditions, and geological mapping, these datasets help clarify how climate change accelerates the degradation of archaeological heritage, and how quickly such sites may disappear. *Model: Tommy Dahl Markussen*



Left: Erosion-exposed graves (red) contrast with graves in more stable terrain (yellow). **Right:** The well-preserved wooden coffin illustrates the exceptional preservation once typical for Arctic burial sites. The site now shows clear signs of permafrost thaw, slope instability, and loss of protective sediments. *Photos: Lise Loktu / NIKU and © The Governor of Svalbard (2019)*

A CALL FOR INTERDISCIPLINARY ACTION

Despite increasing awareness, cultural heritage continues to receive limited attention in climate policy and funding frameworks. Recognising heritage preservation as part of climate resilience is essential. Heritage landscapes contain information about historical risk management, mobility, and adaptation to extreme environments, and they contribute to identity and cohesion in remote Arctic communities. Yet they remain marginal in climate policy, environmental impact assessments, and adaptation strategies. Without targeted action, Svalbard risks losing both material traces and the cultural meanings embedded in its landscapes.

A more integrated approach is needed. This includes long-term monitoring systems for at-risk sites: early-warning tools that combine preservation grading with geomorphological, hydrological, remote sensing, and permafrost data; and rapid-response protocols as degradation accelerates. It also requires closer collaboration between archaeologists, geologists, climate scientists, ecologists, and policy-makers. Such cooperation aligns with the Fram Centre's mission to support solution-oriented knowledge development in the High North.

Protecting cultural heritage is not separate from climate adaptation; it is part of building resilient societies. Heritage provides the long-term perspective needed to navigate rapid environmental change. Without coordinated action, the High Arctic risks losing an irreplaceable archive that connects people, places, and histories across generations. ■

FURTHER READING:

Climarch: Climate-driven degradation of archaeological environments
https://www.niku.no/en/forskningsprosjekt/investigations-of-climate-change-and-degradation-of-archaeological-cultural-environments-in-svalbard-climarch/

OTHER PROJECTS OF RELEVANCE:

Permarich: Permafrost thaw risks for infrastructure and heritage
https://www.norceresearch.no/en/projects/permarich-advanced-mapping-and-monitoring-for-assessing-permafrost-thawing-risks-for-modern-infrastructure-and-cultural-heritage-in-svalbard

Cultcoast: Safeguarding Arctic coastal heritage
https://www.niku.no/en/prosjekter/cultcoast/

Thetida and Sascha: Climate and heritage risk assessments
https://www.niku.no/en/prosjekter/thetida/
https://www.niku.no/en/prosjekter/climate-change-and-heritage-risk-assessments-sascha/

In Longyearbyen, Svalbard's main town, cableway pylons stand close to houses. *Photo: Anne-Cathrine Flyen / Norwegian Institute for Cultural Heritage Research*

Svalbard's cableway pylons are founded on wooden posts driven into the permafrost, making them vulnerable to rot damage at the transition between soil and air. Some pylons stand on steep terrain, others in water. *Photo: Mari Sand Austigard / Mycoteam*

Kathrine Torday Gulden // Norwegian Institute for Bioeconomy Research

Preserving wooden heritage in the Arctic

RESEARCH NOTES

Historic wooden structures across Svalbard are crumbling under the combined weight of climate change and human activity. Longer, warmer, and wetter seasons fuel wood-decaying fungi, while tourism adds physical wear to sites never built to last.

Across Svalbard's windswept landscapes, wooden traces of human history are giving way to climate change and human impact.

In 2021, the ArcticAlpineDecay project set out to understand and counter these threats. Four years later, the project has provided a crucial baseline of knowledge, revealing how vulnerable these cultural landmarks are and why continued monitoring will be essential in the years ahead.

"Svalbard has been our focal point because climate change is unfolding at an extraordinary pace here. It's almost like a natural laboratory," says Anne-Cathrine Flyen, PhD in architecture and technical conservation specialist at the Norwegian Institute for Cultural Heritage Research.

The project also covered Finse on Hardangervidda, where alpine conditions pose similar challenges.

Fieldwork, technical analyses, and interviews with tourists and guides revealed four key vulnerability factors: public understanding, site condition, physical fragility, and patterns of use.

NOT BUILT TO LAST BUT NOW PROTECTED

One of the paradoxes highlighted by ArcticAlpineDecay's coordinator Gry Alfredsen at the Norwegian Institute of Bioeconomy Research, is that many of Svalbard's wooden structures, such as the pylons that support the coal transport cableway, were never intended to endure for generations.

"They were built to serve as long as the mines provided coal, not to last a hundred years," she says. The challenge arose when the Svalbard Environmental Protection Act came into force in 2002, granting automatic protection to everything dating to before 1946.

Suddenly, temporary industrial constructions became cultural heritage, and the responsibility to preserve them for the future became both a legal and practical issue.

Above: Visitors stand in the remains of a cabin at the site of the abandoned marble mine on Blomstrandhalvøya in Kongsfjorden, unaware of the damage they may be doing to the old wooden floor. *Photo: Anne-Cathrine Flyen / Norwegian Institute for Cultural Heritage Research*

Opposite: The cableway from Longyearbyen out toward the loading dock at Hotellneset. *Photo: Anne-Cathrine Flyen / Norwegian Institute for Cultural Heritage Research*

CLIMATE, DECAY, AND TOURISM

Svalbard's cableway pylons were originally founded on untreated wooden posts set into the permafrost, which served as a stable, natural foundation.

However, as the permafrost now thaws deeper each year, the foundation is undermined, threatening the pylons' stability. They are also vulnerable to rot damage in the transition zone between soil and air.

Tourism adds another layer of pressure. Many visitors, often accompanied by guides, are unaware of the vulnerability of these and other wooden heritage sites.

"They tread on, and sometimes through things, without realising they are cultural heritage. Many sites, for example a pile of old wooden planks,

are difficult to read and understand," says Anne-Cathrine Flyen.

Guides tend to focus on history but often lack training in how to protect the physical environment. Simple measures, such as improved signage and barriers, could help reduce damage, but these are not always implemented.

SEVERE DECAY IN MANY PYLONS

A core task in ArcticAlpineDecay was to assess the wooden cableway pylons. The project team took small surface samples (2 × 2 × 5 cm) at both near-ground level and from the pylons' horizontal beams at approximately breast height. This approach minimised impact while yielding sufficient material for analysis.

Other methods included visual inspection, drilling with a thin bit to gauge internal decay and do microscopy, chemical analysis, and DNA metabarcoding.

Of the 22 pylons examined, 17 were severely decayed, with a high risk of collapse. This is a concern, since such structures, if they fail, can endanger people and property in the areas where they are located.

"It's not a question of if, but when some of these structures will fall. The risk is real and immediate," warns Gry Alfredsen.

WOOD FUNGI POSE A GROWING THREAT

DNA sequencing revealed a rich diversity of wood-decaying fungi, with an aggressive brownrot species present in nearly 90% of the pylon samples.

"Brown rot is particularly destructive. Due to its decay mechanism, it causes the wood to lose

Cableway pylons at Hiorthhamn in snow and sunset. The wooden structure around the mine opening and the miners' living quarters can be seen high up on the mountainside on the two sunlit ridges to the right. *Photo: Anne-Cathrine Flyen / Norwegian Institute for Cultural Heritage Research*

strength much faster than, for example, white rot and soft rot," says Alfredsen, adding that this kind of decay likely threatens wooden constructions embedded in soil outside Svalbard as well.

Longer, warmer, and wetter seasons create improved conditions for wood-decaying fungi, accelerating the breakdown of wooden structures.

"When the climate changes, so do the growth conditions for wood-degrading fungi. This can lead to increased risk of decay, even in areas that have previously experienced low temperatures and little precipitation," says Mari Sand Austigard, R&D manager at Mycoteam.

"Knowledge of how fungi behave under different climate conditions is therefore of crucial importance to assess the future risk of failure in wooden constructions, especially those exposed to outdoor conditions."

The project team also detected unexpected species such as shiitake and yellow oyster mushrooms, which may have been introduced through human activity like food waste disposal. This finding highlights the complex interplay between nature and culture at these sites.

MANAGEMENT CHALLENGES—AND ADVICE

In 2023, the Svalbard Museum established a competence centre for cultural heritage. Under agreements with the Governor of Svalbard and the Ministry of Trade, Industry and Fisheries, the centre now advises, monitors, and secures state-owned buildings and sites. These include trapping cabins, mining facilities, and cableway installations, all of which must be regularly assessed and maintained. Previously, these tasks were handled by the Governor and various state owners.

"The Governor still oversees legal tasks under the Environmental Protection Act, but daily preservation remains a challenge," says Anne-Cathrine Flyen. "Large structures like cableway pylons require extensive work, and resources are limited. The Governor's department has only two cultural heritage advisers."

Funding is available through the Svalbard Environmental Protection Fund, yet many sites need attention and better coordination among stakeholders. Flyen recommends: training tourist guides to raise awareness; adding signage and barriers; and applying long-term technical methods for condition assessment.

A BASELINE FOR FUTURE PRESERVATION

Far from being mere relics, the wooden structures scattered across Arctic and alpine landscapes embody human resilience and adaptation to harsh environments.

"They help us put our lives in context," says Flyen, noting that many visitors find that these traces deepen their experience of nature. "Traditional building methods also hold lessons for future resilience as the climate warms."

The results from the ArcticAlpineDecay project, which concluded in December 2025, underscore the urgency of systematic monitoring, better management tools, and clear communication to protect these wooden relics. Safeguarding them will require close cooperation among researchers, heritage managers, policymakers, and local communities.

"We've established a baseline for long-term monitoring, allowing future comparisons that will show how climate change affects northern cultural heritage," says Gry Alfredsen. "Because structures such as the cableway pylons share similar construction, their condition provides important clues about the future of these vulnerable legacies." ■

Top photo: Researchers Anne-Cathrine Flyen and Atle Wehn Hegnes in the abandoned mining town of London on Blomstrandhalvøya in Kongsfjorden, Svalbard, where tourists were interviewed and observed in the field. Although the cabin behind them is protected as cultural heritage, it is still being used, and is therefore maintained in good condition. *Photo: Anne-Cathrine Flyen / Norwegian Institute for Cultural Heritage Research*

ArcticAlpineDecay (2021-2025)

Full name: Deterioration and decay of wooden cultural heritage in Arctic and Alpine environments

Project coordinator: Gry Alfredsen / NIBIO

Project partners: NIBIO, Norwegian Institute for Cultural Heritage Research, Royal Danish Academy, Mycoteam AS, Store Norske Spitsbergen Kulkompani, Kings Bay AS, Norwegian Directorate of Cultural Heritage, Norwegian Trekking Association (Oslo branch), Vestland County Council

Funding: Norwegian Research Council
Webpage: *https://www.nibio.no/en/projects/arctic-alpine-decay*

FURTHER READING:

Alfredsen G, Altgen M, Austigard MS et al (2005) Characterisation of wood decay and fungal diversity in cultural heritage cable car pylons in Svalbard. npj heritage science 13: 463, *https://www.nature.com/articles/s40494-025-02041-x*

Flyen AC, Flyen C, Hegnes AW (2003) Exploring vulnerability indicators: Tourist impact on cultural heritage sites in High Arctic Svalbard. Heritage 6(12): 7706–7726, *https://doi.org/10.3390/heritage6120405*

Bottom photo: During fieldwork in Svalbard, the danger of polar bears is real. When serving as polar bear guard, researcher Anne-Cathrine Flyen must remain active and alert. Here by the cableway pylons in Adventdalen, from Mine 6 to Longyearbyen. *Photo: Brita Flyen Bolin*

Line Rouyet, Elisabeth Angell, Lotte Wendt and Tom Rune Lauknes // NORCE Research AS
Ionut Cristi Nicu, Lise Loktu and Alma E Thuestad // Norwegian Institute for Cultural Heritage Research
Lena Rubensdotter // Geological Survey of Norway
Anatoly Sinitsyn and Yared Bekele // SINTEF AS
Hanne H Christiansen*, **Maaike F Weerdesteijn and Matthieu Leydier** // University Centre in Svalbard

Permafrost thaw threatens Svalbard's cultural heritage and modern buildings

RESEARCH NOTES

Svalbard's cultural heritage and infrastructure face increasing risks as climate change accelerates permafrost thaw and ground instability. The PermaRICH project unites experts across disciplines to evaluate these risks, and guide stakeholders' prioritisation of adaptation and mitigation measures.

* Currently at Aarhus University, Roskilde

Examples of cultural heritage sites and modern buildings in Svalbard.

Far left: Taubanesentralen (old coal cableway hub), Longyearbyen. *Photo: Kathrine Jaklin / NORCE*

Left: House on piles in permafrost ground, Longyearbyen. *Photo: Elisabeth Angell / NORCE*

SVALBARD HOLDS A RICH CULTURAL HERITAGE, with remains from whaling, trapping, exploration, mining, and military activities. These traces form one of the most intact historical archives in the European High Arctic, providing unique insights into past human-environment interactions. Human activity is still extensive today, especially in and around Longyearbyen, Barentsburg, and research stations, such as Ny-Ålesund.

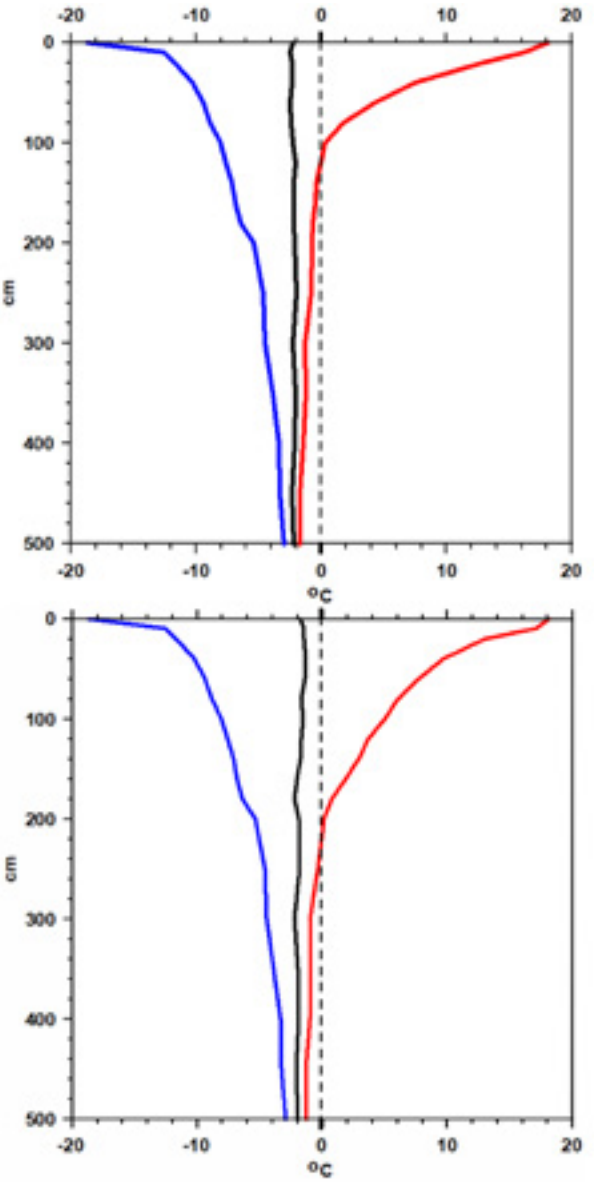
Svalbard's landscape is underlain by permafrost, ground that remains frozen year-round. The overlying active layer thaws each summer, which can cause the surface to sink as ground ice melts. As the Arctic warms, permafrost degradation and active layer thickening intensify ground movement and related hazards, both on slopes and in flat terrain.

For the past three years, the Fram Centre PermaRICH project has studied how permafrost processes and ground movement may affect cultural heritage sites and modern buildings in Svalbard. The project brings together experts from several disciplines–geology, geography, Earth observation, civil engineering, archaeology, and social sciences–to produce new results describing the permafrost conditions, ground dynamics, and their potential consequences in and around Longyearbyen and Ny-Ålesund.

PERMAFROST THAW AND RISK GOVERNANCE

The Norwegian Parliament and the Government devote limited attention to permafrost thaw, although the most recent White Paper on Svalbard (Meld. St. 26 (2023-24)) and a few other documents mention this topic. Norway does not have an agency with overarching responsibility for risk management related to permafrost thaw. While the Norwegian Water Resources and Energy Directorate has responsibility for geohazard monitoring and early warning, the Environment Agency oversees climate adaptation, and the Directorate for Civil Protection oversees preparedness. State sectoral agencies have case-specific responses to threats from thawing permafrost, which depend on their respective mandates. For instance, Statsbygg (which manages government property) focuses on adaptation and mitigation solutions for buildings, Avinor's interventions target risk affecting airport infrastructure, and the Directorate for Cultural Heritage pays attention to the risks imposed by climate change on cultural monuments.

Svalbard authorities, such as the Governor of Svalbard and the Longyearbyen Community Council, show awareness of this topic, considering permafrost thaw in emergency preparedness and climate-related risk assessment. However, high turnover among both residents and public officials limits institutional memory. This challenge increases the need for a comprehensive national approach and support in this field. The agencies with long experience in Svalbard have valuable knowledge to share. Improved coordination between agencies and consistent follow-up of responsibilities would benefit local stakeholders and contribute to a more effective risk governance.



PermaRICH permafrost monitoring activities in Longyearbyen.

Upper row: Borehole being drilled next to a cableway trestle in spring 2023 (left), and the ground temperatures measured in 2024–2025 (right).

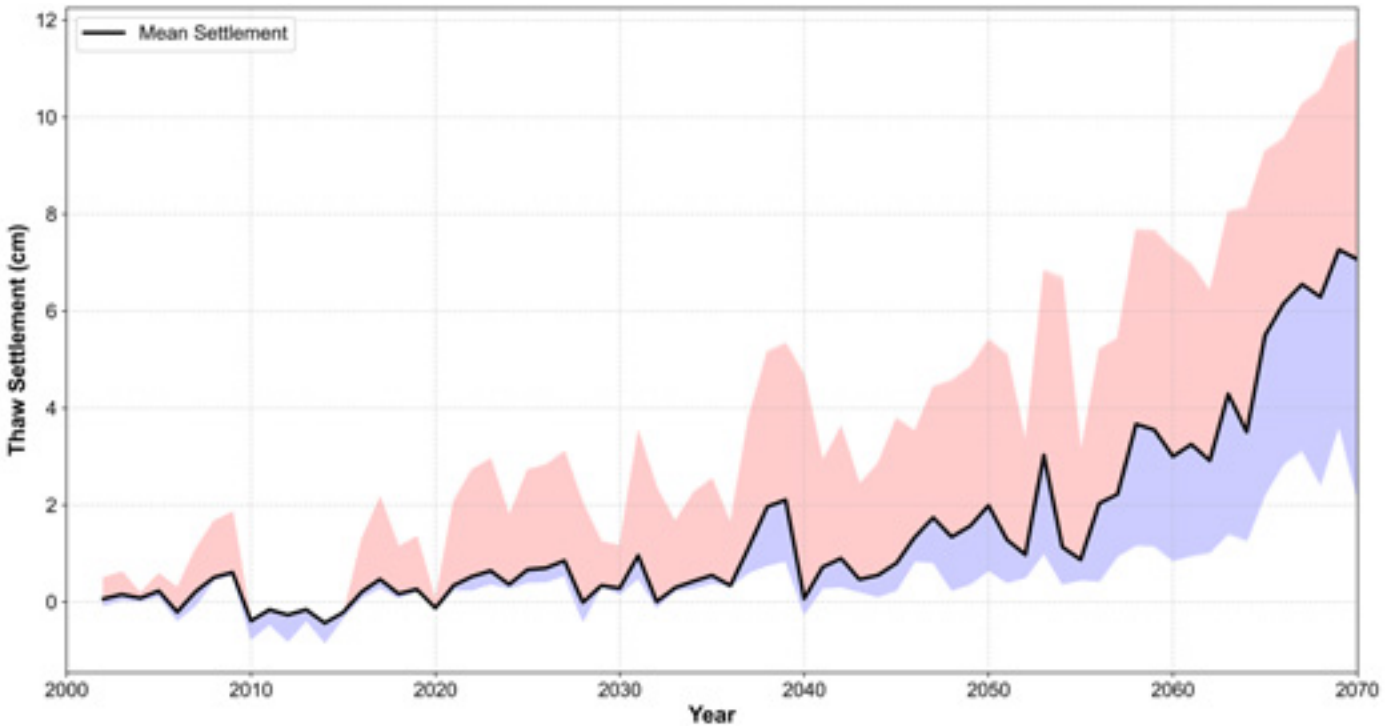
Lower row: Borehole being drilled under the old coal cableway hub in spring 2023 (left), and the ground temperatures measured in 2024–2025 (right). Maximum (red line), average (black line) and minimum (blue line) values. Horizontal axis: ground temperature; vertical axis: depth.

Graphs: Hanne H Christiansen / Aarhus University and University Centre in Svalbard

PERMAFROST CONDITIONS IN LONGYEARBYEN

In Longyearbyen, continuous measurements of permafrost temperatures began only in 2019. Until recently, the permafrost conditions directly beneath cultural heritage objects had not been systematically measured. Thanks to PermaRICH, boreholes down to 5 m were drilled at one cableway trestle and at the old coal cableway hub, both located centrally in Longyearbyen.

We aimed to collect ground samples at these study objects to understand how the permafrost will react in a warming climate. The ground beneath the cultural heritage sites appeared to be much



Predicted evolution of the thaw settlement in Longyearbyen. The thaw settlement remains relatively low and stable until around 2040, after which it begins to increase steadily, with a notable rise in both the mean value (black line) and the variability (shaded area). By 2070, the settlement might exceed 10 cm based on the most extreme scenarios.

Graph: Yared Bekele and Anatoly Sinitsyn / SINTEF AS

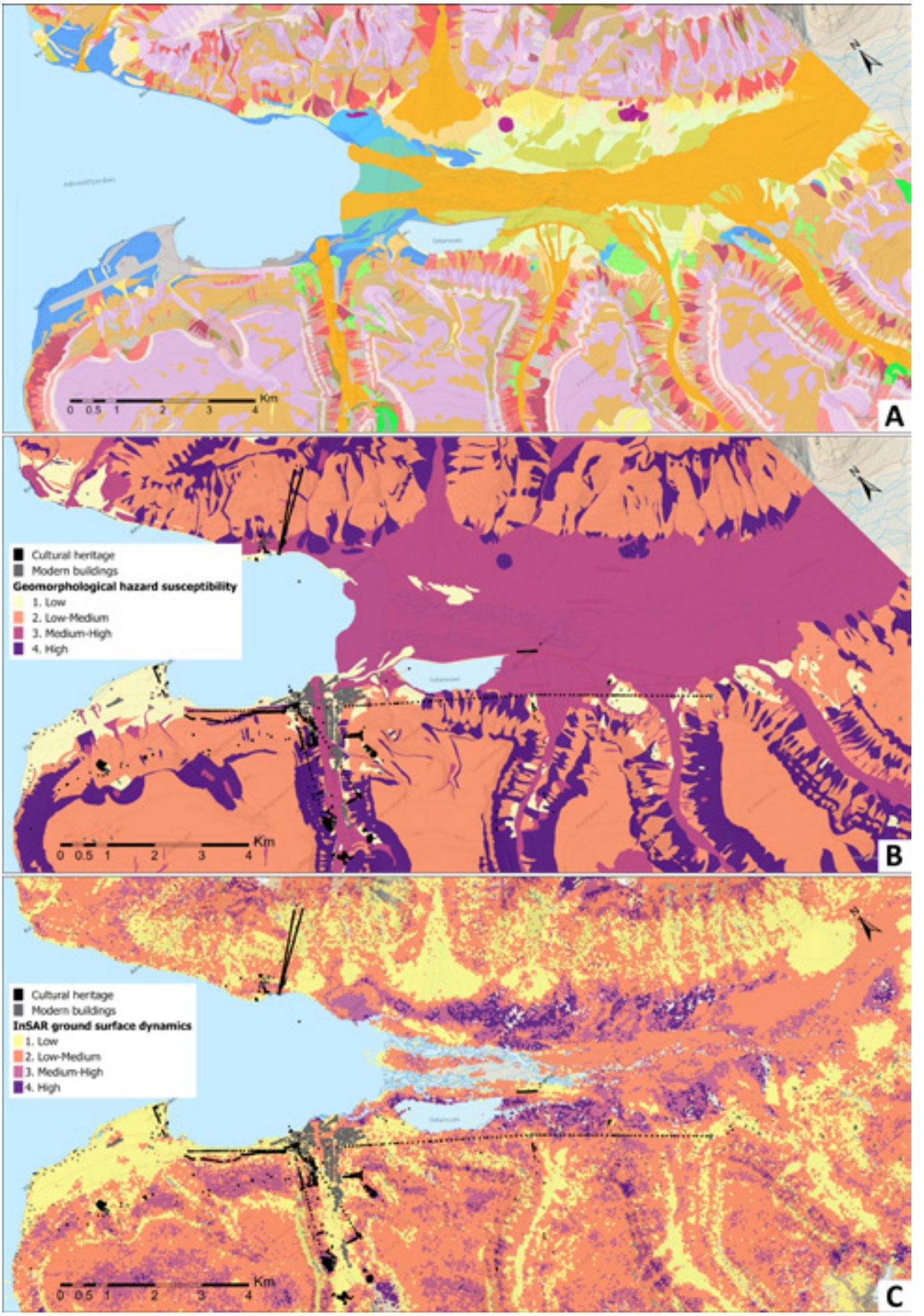
looser and more disturbed than natural sediments in other parts of Longyearbyen, where cores had been collected previously. Therefore we were unable to collect frozen cores for analyses. This lack of success at coring indicates a relatively low ice content, and suggests that future permafrost thaw is unlikely to cause large-scale sinking at these locations.

Temperature sensors were installed in the boreholes, and the measurements show that the permafrost in these areas is relatively warm, between 1.3°C and 1.7°C at 5 m depth. The active layer is about 1-2 metres thick, which is within the average for the Longyearbyen permafrost boreholes.

CLIMATE PROJECTION AND SETTLEMENT

We studied how climate change, thawing permafrost, and melting ground ice could affect the stability of buildings and cultural heritage sites in Longyearbyen and Ny-Ålesund. Climate projections indicate steady warming through 2070, leading to thicker active layers and higher permafrost temperatures. We examined how these changes may influence two main types of processes: thaw settlement, which happens when ground ice melts, and creep settlement, which is the gradual deformation of frozen soil under a sustained weight. These effects were studied for buildings with different foundation types.

The results show that the active layer will get thicker, causing more thaw settlement of the ground. For buildings on piles, the part of the piles that stays frozen will get shorter, reducing how much load they can safely hold. Creep settlement is smaller but still adds to the total movement. For shallow foundations, both thawing and creeping may cause more noticeable settlement. Overall, the study shows that ground deformation due to climate warming could threaten the long-term stability of structures in Svalbard.


0 0.5 1 2 3 4 Km
A
Cultural heritage
Modern buildings
Geomorphological hazard susceptibility
1. Low
2. Low-Medium
3. Medium-High
4. High
0 0.5 1 2 3 4 Km
B
Cultural heritage
Modern buildings
InSAR ground surface dynamics
1. Low
2. Low-Medium
3. Medium-High
4. High
0 0.5 1 2 3 4 Km
C

New maps for hazard assessment in Longyearbyen and Adventdalen.

A) New geomorphological map following the Norwegian SOSI-standard for Quaternary geological maps, with adaptation to the Arctic setting and the PermaRICH objectives.

B) Four levels of geomorphology-based susceptibility to permafrost-related hazards (low-high).

C) InSAR simplified map showing four levels of ground dynamics (low-high) from seasonal and interannual surface movement.

Maps: Lena Rubensdotter / Geological Survey of Norway and Line Rouyet / NORCE

ASSESSMENT OF NATURAL HAZARDS

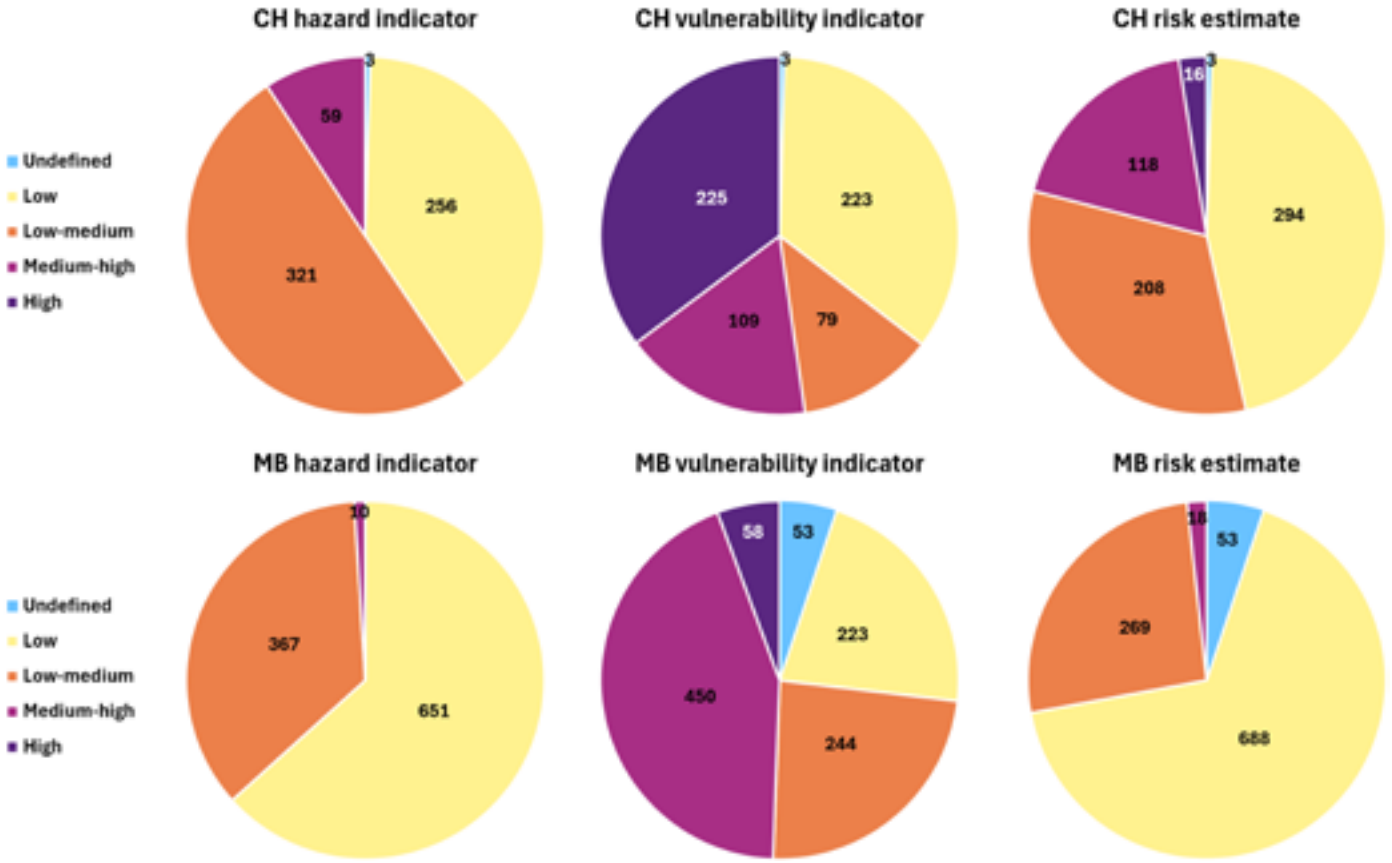
A wide range of natural processes can endanger cultural heritage and modern buildings in permafrost terrain, such as subsidence due to ground ice melt, landslides, rockfall, debris flows, floods, erosion along rivers and coastlines, etc. The first step of any hazard analysis is to map the type, location, and distribution of processes and surface material. We used modern aerial images, old maps and field visits to create new geomorphological maps that show the distribution of landforms, processes, and deposits. These maps were then used to make indicators documenting where permafrost-related processes might pose threats to cultural heritage and buildings.

In addition, we used an advanced measurement technique, called InSAR, that compares satellite images taken at different times, to measure how the ground surface is moving through the summer and from one year to another. Together, the geomorphological and the InSAR ground movement maps form a base that enables a combined evaluation of several natural hazard types. The maps on page 38 illustrate some of the new data for the Longyearbyen and Adventdalen area. Similar datasets have been produced for Brøggerhalvøya and Ny-Ålesund.

VULNERABILITY ASSESSMENT

Vulnerability is defined as the likelihood that a person or an object could be harmed when something dangerous occurs. We analysed 639 cultural heritage sites and 1028 modern buildings in and around Longyearbyen, and 90 cultural heritage sites and 128 modern buildings in Ny-Ålesund. In PermaRICH, we have developed a qualitative score from 1 (low) to 4 (high) to document the level of sensitivity of the studied sites and buildings.

The criteria used to evaluate the potential for damage are different for cultural heritage and for modern buildings. For cultural heritage, we analysed the type, shape and material of the protected historical remains. We evaluated how each category would be affected by permafrost-related hazards. For modern buildings, vulnerability was determined by usage and community function. Some overlap exists. Some heritage buildings are still in use today and were therefore assessed using both frameworks, reflecting different factors for analysing vulnerability in terms of historical value and population exposure.



Hazard, vulnerability and risk qualitative estimates in Longyearbyen. Such results can also be viewed on a map, to analyse specific locations or focus on objects with the highest scores.

Upper row: Distribution of the indicators for 639 cultural heritage (CH) sites.

Lower row: Distribution of the indicators for 1028 modern buildings (MB). Similar estimates have been developed for Ny-Ålesund.

Graphs: Ionut Cristi Nicu / Norwegian Institute for Cultural Heritage Research, Line Rouyet / NORCE, and Lena Rubensdotter / Geological Survey of Norway

INTEGRATED RISK ASSESSMENT

Risk is defined as the likelihood that something bad happens, based on how dangerous a situation is and how vulnerable the people or objects are. In PermaRICH, we developed an indicator combining the results of the permafrost-related hazard analysis and vulnerability assessment. The risk estimate is qualitative and relative. It is a way to summarise the information, to complement local knowledge and other management criteria when prioritising concrete measures. The risk estimates will be communicated to the local stakeholders, together with all initial maps and intermediate indicators, so that the results can be tailored to different applications.

CONCLUSIONS AND PROSPECTS

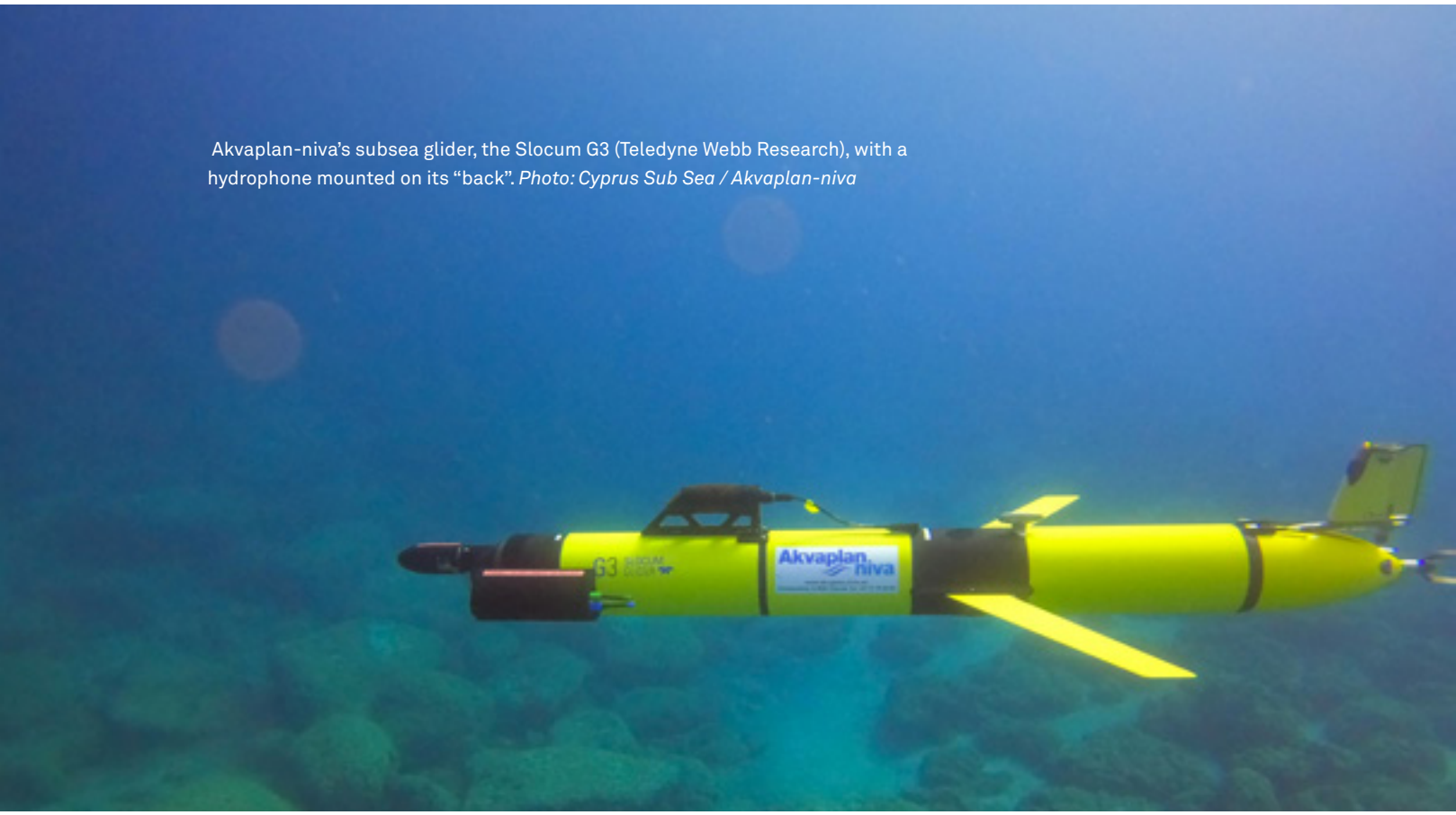
The PermaRICH project gathers and analyses a wide range of new information on permafrost, natural hazard and risk in Svalbard. The team is now working to make all data and results freely available, so they can be drawn upon by local users in Svalbard. We hope that our work will contribute to the management of valuable historical sites, and support suitable solutions for improving public safety and maintaining sustainable economic activity in Svalbard. ■

FURTHER READING:

PermaRICH project webpage: *https://www.norceresearch.no/en/projects/permarich-advanced-mapping-and-monitoring-for-assessing-permafrost-thawing-risks-for-modern-infrastructure-and-cultural-heritage-in-svalbard*

Bekele Y, Sinitsyn A (2025) Evaluation of foundation settlements for selected cultural heritage structures under climate change impacts. SINTEF report 2025:00370. ISBN: 978-82-14-07476-5, *https://www.sintef.no/prosjekter/2023/permarich/*

Angell E (2024) Myndigheters policy om tining av permafrost og skred i Longyearbyen. Report no. 1, NORCE. (In Norwegian with brief summary in English). *https://hdl.handle.net/11250/3128621*



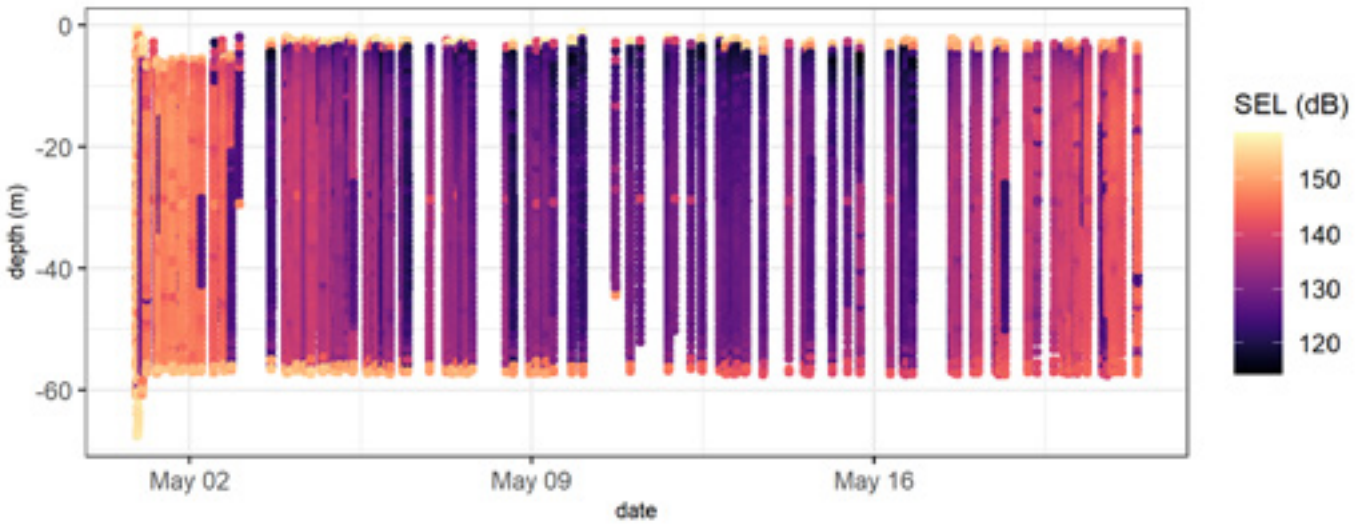
Akvaplan-niva's subsea glider, the Slocum G3 (Teledyne Webb Research), with a hydrophone mounted on its "back". *Photo: Cyprus Sub Sea / Akvaplan-niva*

Virginie Ramasco and Katherine Dunning // Akvaplan-niva
Geir Pedersen and Tonje Nesse Forland // Institute of Marine Research

Using gliders to assess the sonic footprint of marine seismic surveys

RESEARCH NOTES

Marine seismic surveys use high-intensity low-frequency underwater sound waves to map sub-seabed structures, such as oil reservoirs. These sound waves travel long distances, requiring large-range measurements to assess their environmental impact, including potential disturbance of marine fauna.



Estimated sound exposure levels (SELs) from the glider deployment before data cleaning. The highest SELs are at the surface and at the dive's maximum depth, when the glider changes tilt and buoyancy. SELs also progressively decreased and then increased again as the glider moved away from the sound source and back to assess noise levels at different distances. *Graph: Virginie Ramasco / Akvaplan-niva*

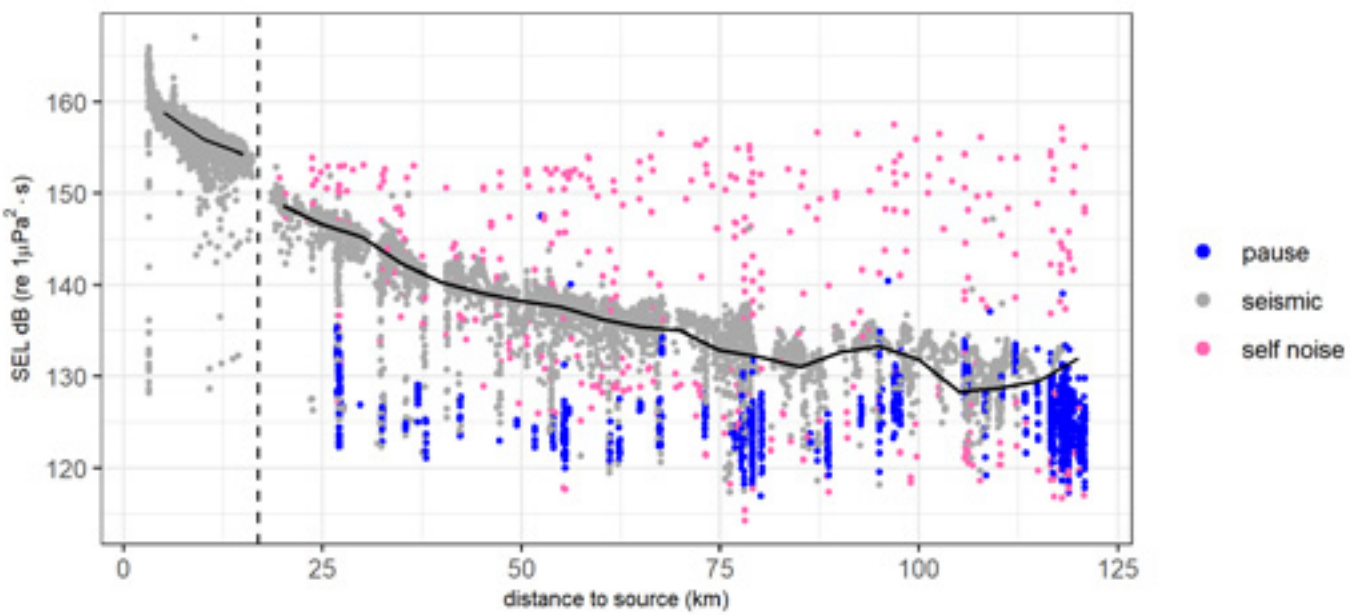
Seismic surveys are frequently used for oil and gas (O&G) exploration, exploitation, and monitoring, not least in the North Sea, where many marine animals also live. The Glider II project, run by Akvaplan-niva in collaboration with an industrial O&G company, was aimed at investigating if the use of autonomous glider platforms for applied scientific research could support operational challenges in the O&G industry. One of the sub-objectives of the project was to test if gliders could be used in passive acoustic monitoring of seismic operations. Passive acoustic measurements can be helpful in studying the sound propagation from the source, the exposure levels at different distances and, ultimately, the impact of such exposure on marina fauna.

For this purpose, a subsea glider equipped with a hydrophone was deployed during one of the regular seismic surveys performed by the O&G industry to monitor the status of the reservoirs at an extraction site in the North Sea. Around these O&G installations, a seismic survey is regularly performed in an area of ~12 × 8 km. During these surveys a seismic vessel operates continuously for several weeks running up and down parallel survey lines within that area, performing seismic shots every 25 metres (about every 10 seconds) to map the underground reservoirs.

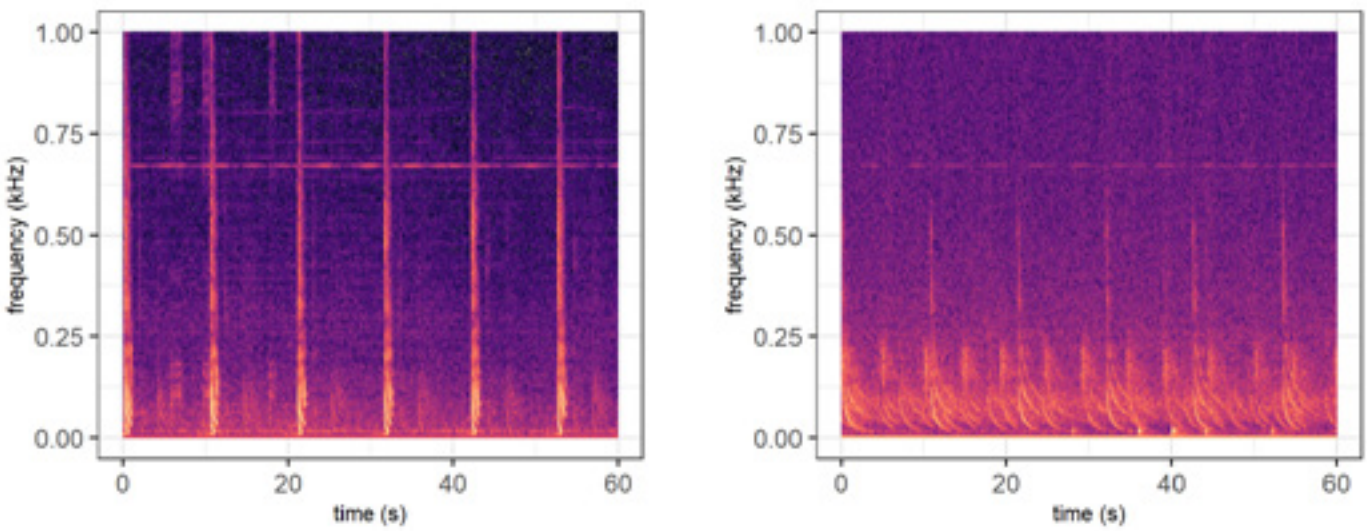
During the seismic survey in spring 2022, Akvaplan-niva's autonomous subsea glider was used to measure the sound levels throughout the water column between ~20 and ~120 km distance from the operating seismic vessel (i.e. the sound source). The objective was to assess whether seismic shots could be reliably detected above background noise levels at such distances. We also wanted to test if this vehicle was a reliable platform for this purpose under operational conditions.

After recovery of the glider, the sound measurements were downloaded and analysed to evaluate the main sources of noise interference and to isolate the sound attributable to the seismic shots. Subsea gliders are very silent platforms highly suitable for passive acoustic monitoring. However, due to internal changes in buoyancy and pitch, they do produce some noise. The noise usually occurs during the shifts between downward and upward gliding or vice versa. These shifts mostly take place near the ocean surface and at maximum diving depths; thus most of the internal noise was at specific depths, which made it easier for the scientific team to identify and eliminate noise by filtering the data from those depths.

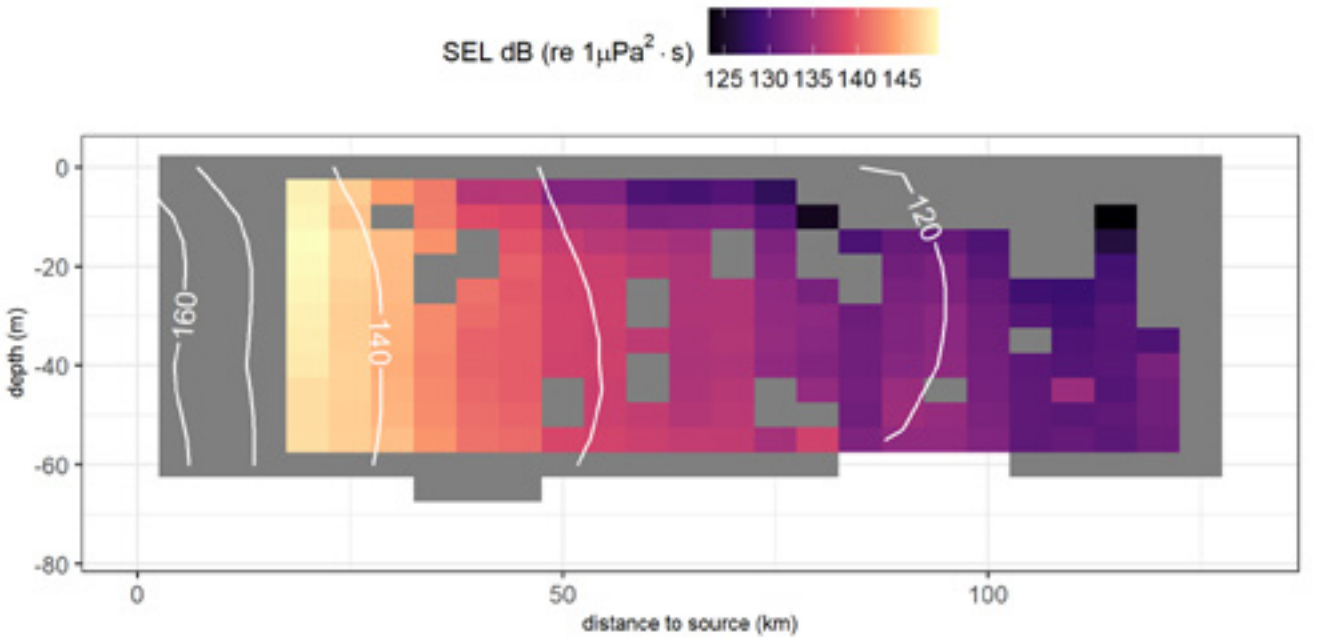
Sound Exposure Levels (SELs) were calculated from the cleaned data. These are a measure of the sound intensity integrated over a period of time. In this example 10 s was used as integration period, which roughly corresponds to the time between subsequent shots. SELs provide a quantification of the marine habitat exposure to sound and are important in environmental impact assessments.



Classification of sound exposure levels measured by the subsea glider. The pink dots show the SELs identified as self-noise, which do not decrease in intensity with distance from the seismic source, confirming that they cannot be attributed to seismic shooting. Seismic noise (grey) at distances closer than ~17 km (dashed vertical line) was measured by a moored hydrophone. Background noise (blue) was relatively constant across distances. *Graph: Virginie Ramasco / Akvaplan-niva*



Spectrograms showing seismic shots measured by the glider's hydrophone at 20 km (left) and 120 km (right) from the sound source. The scale from dark to light colour represents increasing sound intensity. *Graph: Virginie Ramasco / Akvaplan-niva*



SEL values shown along distance from the source and depth. Note the decay of sound intensity with distance and the differential propagation at surface and at depth. *Graph: Virginie Ramasco / Akvaplan-niva*

An estimate of the general background noise of the area was done by calculating SELs in periods where seismic activity was paused. This occurred regularly throughout the survey. The sound above background noise during periods of active seismic shooting was attributed to seismic activity. The resulting classification of estimated SELs over time was compared to a nearby moored hydrophone for quality assurance. SELs showed a realistic decaying pattern with distance from the sound source and were consistent with the absolute values measured by the hydrophone at the mooring.

Seismic shots were identifiable in the spectrograms (i.e. images of the sound intensity by frequency and time) at both ~20 km and ~120 km distance. At 20 km, shots are visible as separate higher intensity sounds at 10-second intervals. At 120 km, sound waves from the same shot arrive at the receiver (i.e. hydrophone on the glider) at different times due to reflections and refractions on their path; hence each shot is not clearly identifiable in time. Seismic activity is, however, still clearly visible at this distance and SEL values are higher than background noise.

These measurements can be used in understanding the exposure of marine animals at different distances from the seismic source, to validate sound propagation models and to link exposure to a potential effect on animals. The innovative aspect of subsea glider technology lies in their ability to provide multi-dimensional information, not only with distance from the sound source, but also throughout the water column. Our study confirmed that such platforms offer an efficient, cost-effective, low-carbon solution for noise level monitoring with both spatial and vertical components.

The measurements from this particular deployment showed that sound propagated further at mid ocean depths, and not as much along the bottom and at surface. This kind of information is of great value for validating models of sound propagation, particularly at large distances to support the understanding of the environmental impact of seismic operations. These measurements were used to compare different sound propagation models and choose the more reliable model in estimating sound exposure. Results obtained with this specific application have been written up and are currently in peer review. ■

Ane K Engvik, Håvard Gautneb and Janja K Solberg // Geological Survey of Norway

Graphite – a mineral for our future

RESEARCH NOTES

The Geological Survey of Norway is doing field work in the north of Norway to map old gneisses and granites. Among these major rock types, we find another type, schist, which can be rich in graphite, a mineral that is critical for our modern lifestyle.

Graphite is recognised by its ability to colour your thumb grey. *Photo: Ane K Engvik / NGU*

Remnants of mining activity near Sortland, where graphite was previously mined. *Photo: Ane K Engvik / NGU*

Shiny silver-black crystals of flake graphite.
Photo: Håvard Gautneb / NGU

Sometimes called the black silver of northern Norway, graphite is usually difficult to recognise, as it tends to lie hidden in vegetated areas or as crumbled rock on beaches along the seashore. But geologists' perceptive eyes know what to look for. Where the schist is rich in graphite it takes on a silver-black shiny look. We rub a shiny black rock face with a thumb, and if the thumb comes away grey, we know that the schist is rich in graphite.

Graphite consists exclusively of the element carbon (C) and is among the softest minerals known to science. Its physical properties are controlled by its crystal structure. The lattice of carbon atoms in graphite is structured as thin layers that slide easily along each other. This is precisely what happens when we write with a pencil: the "lead" of a pencil is actually graphite, which sheds layers when scraped against paper. The same thing happens when we use our thumb to test for graphite on the rock face.

A CRITICAL RAW MATERIAL

The graphite deposits in northern Norway have been known for a long time; some of them, for instance those in Vesterålen, were mentioned back in the 1850s. Old mine shafts, weathered wooden frameworks, sealed drill holes, and overgrown slag heaps guide us to sites where graphite mining once took place. But since then, our knowledge about and use of the mineral have changed.

Today, graphite has become an attractive mineral, for which geologists are searching once again. It has been classified as a "critical raw material" because of its economic importance and the realisation that changes in geopolitical conditions can make its access uncertain. At Senja in Troms, one of the most important graphite mines in Europe is running today.

The precursor to graphite is most commonly organic matter formed by photosynthesis. Graphite formation (graphitisation) is essentially a two-step thermal process: at increasing temperatures, non-carbon components (hydrogen and water) are removed first; at temperatures above 700°C all organic matter is converted to graphite. If the graphite is incorporated with other minerals, such as quartz and feldspar, so-called flake graphite is formed. Our work on mineral characterisation and isotopic measurements of graphite in northern Norway confirm this origin. This geological environment is what we find in the gneiss areas of northern Norway, where the rock was formed and transformed at high temperatures deep in the crust millions and billions of years ago.

TRACEABLE UNDER LAND AND WATER

Graphite deposits are normally hidden in overgrown areas—not only because graphite schist crumbles easily, but also because it often occurs together with carbonate rocks that provide good conditions for vegetation. That is why we need to search to find graphite. Fortunately, modern methods aid us in the search for new graphite deposits.

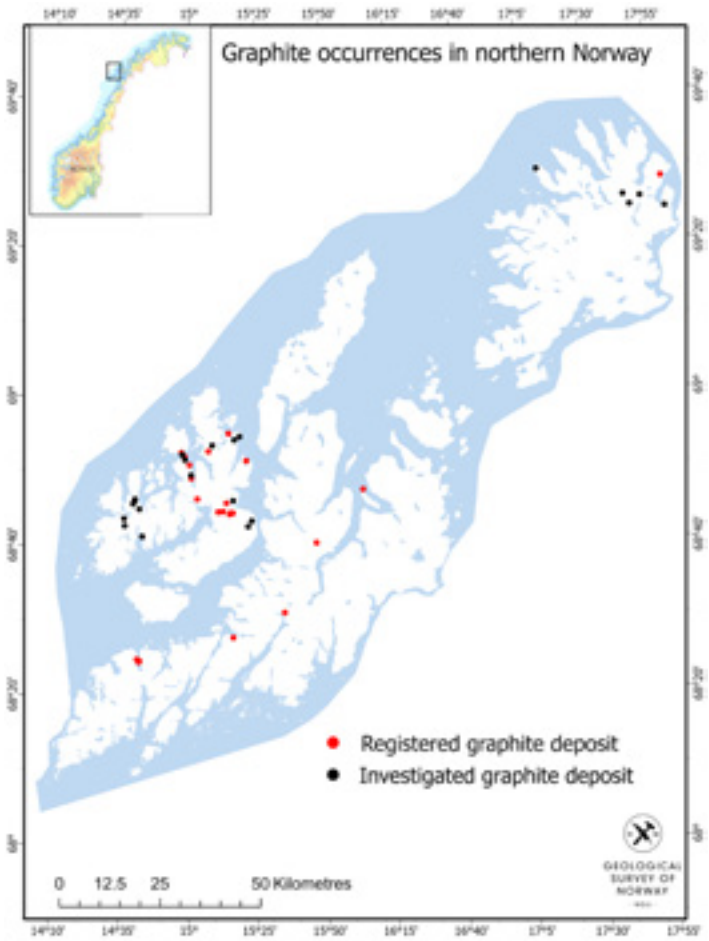
The Geological Survey of Norway (NGU) has been remapping the graphite deposits in Senja and Vesterålen since 2012. This work is still highly relevant. Graphite is a good electrical conductor. Therefore, geophysical surveys using planes and helicopters carrying equipment to measure electrical conductivity are essential in detecting areas with graphite. Potential graphite zones can be traced through mountains, under marshes, and across fjords. With support from the relevant municipalities, the mineral exploration is followed up on the ground with more detailed investigations, bedrock drilling, and rock sample collection. This work has involved NGU's geophysicists, mineral resources experts, bedrock geologists, and laboratory scientists working together.

CAN'T GROW IT OR HUNT IT? MINE IT!

From early historical time bedrock has been used as a resource and has contributed to the development of civilizations. Today, we use raw materials from the bedrock in all parts of modern life, in buildings and transportation, but also in the most everyday tasks. With the current demand for green energy solutions, there is a need for new mineral resources to continue development of our society.

Graphite is used as lubricant, in metallurgic industry, and in the chargeable batteries that power the electric transport revolution. This shiny silver-black mineral is crucial for modern society. ■

Among the common hard gneissic and granitic rocks of Vesterålen (brown rock face to the right), we find crumbled schists with black layers rich in graphite (black rock under the hammer).
Photo: Ane K Engvik / NGU



Mapped graphite deposits in northern Norway.
Map: Geological Survey of Norway (NGU)

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Close to shore: A side-mounted multibeam echosounder on the small RV *Clione* allowed for gas mapping in shallow waters (June 2021). *Photo: Nil Rodes / University Centre in Svalbard*

Per Olav Solberg // Geological Survey of Norway

Methane beneath Svalbard may be an underestimated climate risk

RESEARCH NOTES

Researchers have discovered hundreds of methane gas emissions in the fjords around Svalbard. They are now working to understand what controls this activity, and what the findings can tell us about future methane releases in a warming Arctic.

In Longyearbyen, temperatures have risen by more than seven degrees over the past 25 years. As permafrost thaws and the landscape changes, researchers are beginning to observe geological dynamics that have long been overlooked. Beneath Svalbard lie significant amounts of natural gas. And in the fjords, where the permafrost "lid" is absent, the gas freely bubbles up to the surface, where it can potentially contribute to further warming.

HUNDREDS OF GAS FLARES FOUND

In 2021, master's student Nil Rodes at the University Centre in Svalbard (UNIS) and researcher Peter Betlem (now at NGI, the Norwegian Geotechnical Institute) chartered a small research vessel. Their goal was to conduct the first natural gas surveys in Isfjorden since 2015. Expectations were low, as the published scientific literature indicated that very few gas seeps had been documented in that area. However, data from a 2015 research cruise led by the Center for Marine Environmental Sciences at the University of Bremen (MARUM) suggested otherwise. With simple instruments and measurements funded by an Arctic Field Grant from the Research Council of Norway, Betlem, Rodes, and their team confirmed that the fjord was indeed full of gas seeps.

"We found hundreds of flares across the entire fjord. The geological system beneath Svalbard is far more active than we previously thought," says Betlem.

The findings not only challenged the existing literature but also raised a series of fundamental questions that had not been addressed previously. Betlem describes it like this:

"We saw hundreds of flares, but we had no idea what was driving them. How deep was the gas coming from? How much was escaping? Was there temporal variation? And why did some flares pulse and disappear within hours?"

Spring fieldwork: Nil Rodes (left) and Peter Betlem in Bünsow Land. Onshore surveys lay the foundation for the marine research cruises. *Photo: Nil Rodes / University Centre in Svalbard*

A SYSTEM IN CONSTANT CHANGE

The research team also lacked answers on whether the variations were linked to temperature changes, pressure changes, potential gas hydrate dissociation, or specific structures in the bedrock. These knowledge gaps necessitated further investigation, and the proof-of-concept study led to a joint MARUM-UNIS research cruise in September 2023 on board Germany's *Heincke* research vessel-the same vessel as in 2015. This time, the objective was to systematically survey Svalbard's western fjords for further evidence of seepage. Building on data from all three surveys, Rodes recently initiated a PhD project to investigate the extent of seepage and the reasons behind the dramatic variation in methane emissions.

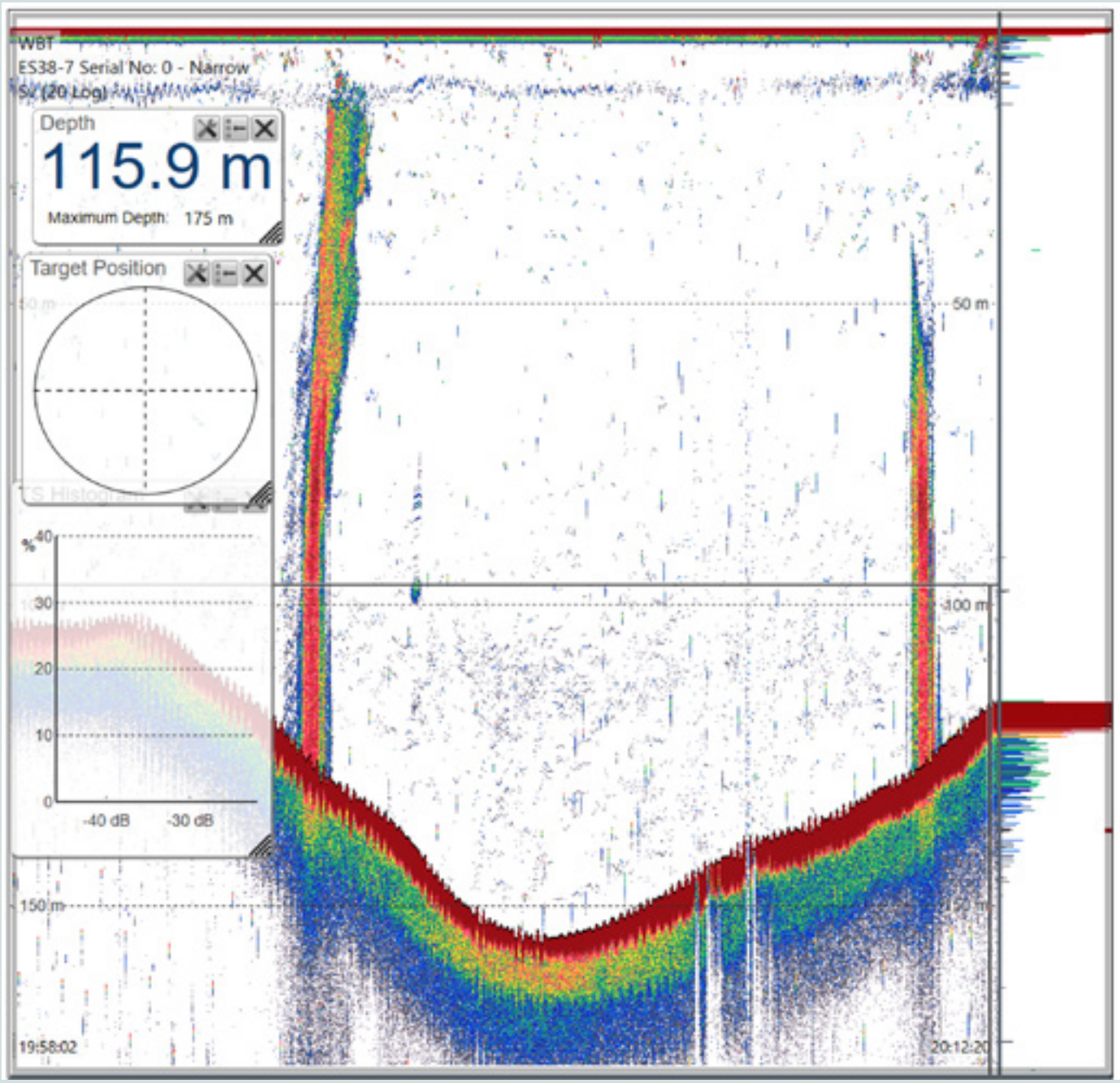
"We know that there is a lot of gas, and we know that it escapes into the fjords. But we still don't know what actually controls the variability across the fjord," says Rodes.

SEEING THINGS WE CANNOT SEE ON LAND

Rodes' PhD is part of an international collaboration, including NGI, UNIS, MARUM, UiT The Arctic University of Norway, and the University of Barcelona. The goal is to understand what fluctuations in the fjords reveal about the processes unfolding beneath the permafrost on land. "The geology is the same, and the petroleum system is the same. Having said that, it is challenging to measure gas escape directly on land," Rodes explains.

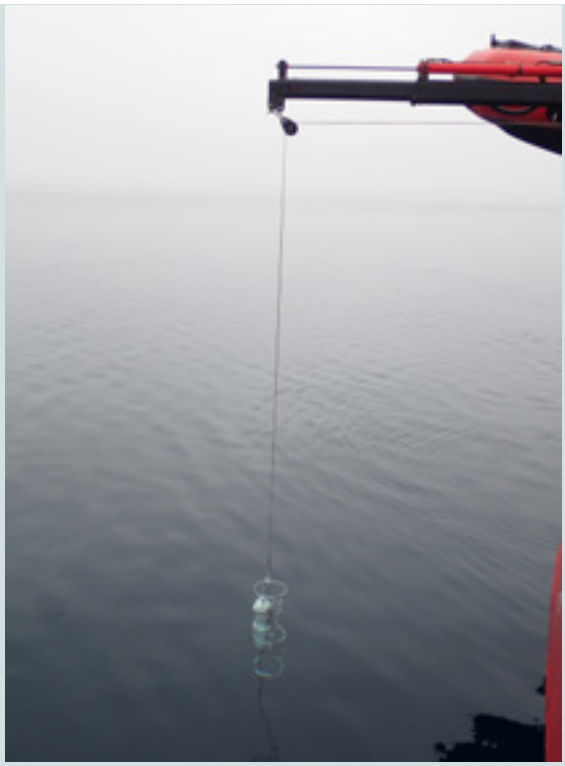
In the fjords, however, the researchers can literally *observe* the bubbles escaping from the fjordbed. This active seepage allows testing hypotheses about pressure, temperature, gas hydrates, and faults and fractures that may act as pathways for gas migration.

"The fjords act as a natural laboratory. They help us understand conditions beneath the permafrost without drilling or excavating into the tundra," says Betlem.



Revealed by sound: The echogram shows gas bubbles (red/yellow) rising from the seafloor. The flare on the left is strong enough to reach the surface. *Illustration: University Centre in Svalbard*

Real-time analysis: Peter and Nil processing hydroacoustic data onboard the research vessel RV *Heincke* in Isfjorden, September 2023.
Photo: Miriam Römer / University of Bremen



Profiling the water: A CTD probe is lowered (June 2021) to measure salinity, temperature, and depth.
Photo: Nil Rodes / University Centre in Svalbard

DOES THIS MATTER FOR THE CLIMATE?

Methane has a 25 times stronger greenhouse gas effect than CO_2. In deep fjords, some of the methane dissolves and reacts with oxygen in the water, breaking down, and thus little–if any–of it reaches the atmosphere. However, in shallower areas, such as those closer to shore, the opposite occurs: methane may escape directly into the air because it doesn't have time to dissolve in the water column.

Today, researchers estimate that methane emissions from groundwater springs formed after glacial retreat (so-called glacial forefields) already account for around 10% of Norway's annual energy-sector emissions.

"We know that methane exists beneath the permafrost on land; numerous boreholes have confirmed it. The big question is how a weakening permafrost barrier will affect potential leakage pathways," says Betlem.

AN URGENT RESEARCH CHALLENGE

This is not about the entire permafrost system collapsing at once. Even in a rapidly warming Arctic, the thickest permafrost layers in the mountains are expected to remain intact for centuries. The real risk lies elsewhere: in the localised weaknesses that can form long before the main body melts.

"In Svalbard's valleys, the permafrost is relatively thin and young, in places only a few thousand years old, and therefore much more vulnerable to warming and degradation," says Betlem.

Here, minor breaches in the permafrost (so-called taliks) can form over years or decades, and even

Seafloor monitoring: Deployment of a "sonar lander" to study the temporal variability of gas emissions (September 2023). *Photo: Max Marklein / University of Bremen*

METHANE IN THE SVALBARD FJORDS

The findings:
Hundreds of methane gas seeps have been recorded in the fjords around Longyearbyen. The greenhouse gas effect of CH_4 is 25 times higher than that of CO_2.

Why emissions occur at sea:
The permafrost layer, which acts as a barrier to upward fluid migration on land, is largely absent in the fjords, allowing gas to escape more easily.

The situation on land:
Boreholes show significant amounts of gas beneath the permafrost, but researchers still know little about how, if, and when this gas might begin to leak.

Why fjords are essential to study:
Fjords offer a unique window into processes that are difficult to observe on land. The permafrost acts as a tight lid on the tundra; in the fjords, that barrier is absent, and the gas may escape.

more rapidly in front of retreating glaciers. Such early openings may create new pathways for methane to rise to the surface and, in the worst case, trigger reinforcing local processes.

"Once cryosphere degradation begins to break up the permafrost lid, the process can reinforce itself and set off a chain reaction. This is what we are trying to understand before it happens," he explains.

For Rodes, the PhD project is ultimately about giving both scientists and society a stronger foundation for decision-making.

"When we understand the fjords better, we can also understand what might happen on land, and what we risk in a rapidly warming Arctic," Rodes concludes. ■

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Ann Eileen Lennert // UiT The Arctic University of Norway

Art-based research for holistic awareness of social–environmental relations

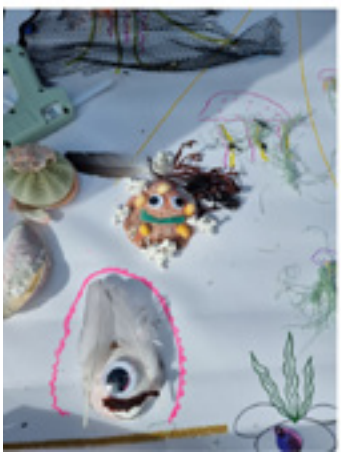
SCIENCE AND SOCIETY

Art and creativity can bring people together and help them communicate ideas beyond social boundaries. Art offers an inclusive space to explore one's own thoughts and share them without being confrontational. It can help us find new ways to express ourselves when words fall short.

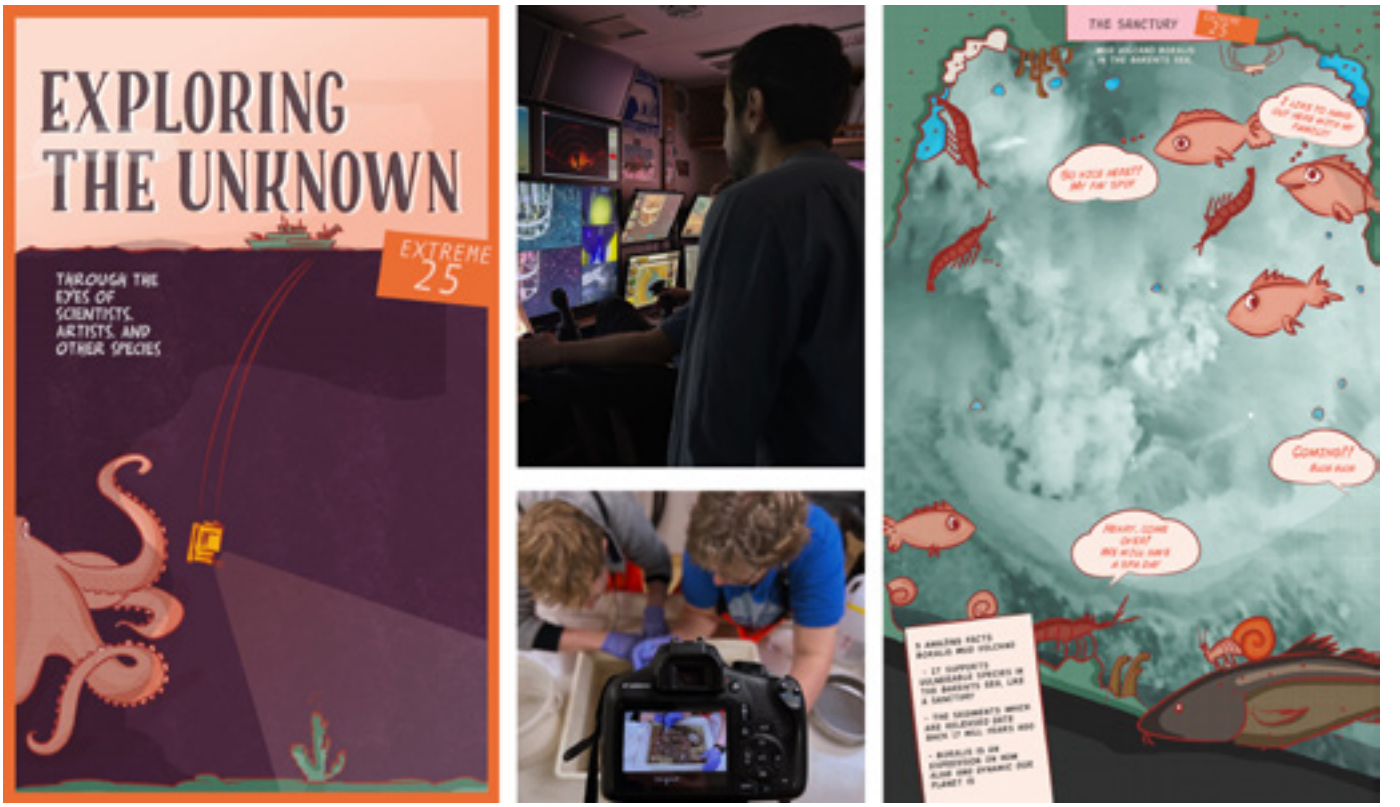
In art-based research, art is not merely the subject, but a tool used in every step of the research process, to ask questions, collect information, understand what it means, and show the results. Art engages people's imagination, emotions and senses, to explore complex, personal, and hard-to-measure aspects of life, transcending the cognitive to elicit unspoken knowledge. Art often provides deeper, more relatable insights, reaches broader audiences, and reveals hidden meanings beyond the reach of traditional research.

Art-based research can also diversify common approaches to community science by opening for creativity and play–inviting people to draw, take photos, sing, dance, or simply sit together knitting. Like science, art is an expression of curiosity. By deliberately bringing art and science together, we expand our ways of questioning the world–asking why things are the way they are, and approaching reality imaginatively.

This paper briefly explores two projects in which we used the arts to investigate layers of experience and knowledge that cannot always be expressed in words, collecting and communicating the complexity of interactions between humans and nature, and the societal challenges we face today and in the future.



Creative workshops can give youth and children space to express how they connect to the sea and how they understand the role of biodiversity and human impacts. During these workshops 86% said that the sea and coast make them feel very happy because of all the animals and hidden gems. The majority wanted the coast to be as it is today so they can share it with their own family in the future. *Collage: Ann Eileen Lennert*



During our research expedition in November 2025 we used comics and photography to explore and disseminate different ways of knowing, engaging and researching extreme environments. *Illustrations: Jane Zimmermann and Ann Eileen Lennert. Photos: Valentina Lanci*

IMAGINE THE DEEP SEA

The ocean and coasts have shaped our lives. They have been a means of travel, a treasure trove of resources and food, and have shaped many cultures that have settled along the boundary between land and sea. Yet we yearn to explore more, and due to our close ties to the ocean, we are exploring deeper.

History shows that exploration and exploitation have long been entwined, not least in the deep sea, now touted as a vast source of minerals. But what if insight into nature can change us, our relationship and appreciation, rather than us reshaping environments to suit our needs?

In the darkness of the deep lie entire ecosystems based on the biochemical powers of colourful microbes, worms, benthic creatures rushing up and down the water column every day, and snails with suits of shiny armour, ecosystems important for the species and ecosystem services we depend on. Ironically, if we do not take precautions for future management, the deep sea might become as empty and lifeless as we once imagined it to be.

In the Extremes project we use art to kindle the imagination of audiences, as we believe that imagination can give nature a voice by helping us perceive, translate, and advocate for ecological realities that aren't easily heard in human terms. We now have an opportunity to forge a

The Extremes project and expedition also contributed insights to a children's book on imagining and exploring extreme environments. *Illustrations: Jane Zimmermann*

new relationship with the living planet, and we wish to foster knowledge, awareness, and a sense of care for the unique deep underwater world. This doesn't replace science–it complements it by making complex systems legible, relatable, and morally salient. Only when nature has a voice do we become aware that our actions always come at nature's expense. Humans are undeniably entwined with nature, an entwinement that, in turn, shapes diplomatic and political discussions about the ocean's future.

Even today, imaginaries* of the deep sea remain a blend of scientific, cultural, and fictional ideas. Therefore, creating an interdisciplinary team of natural scientists, anthropologists, and artists to develop new ways to sense, understand, and imagine the significance of these extreme marine environments in the Arctic was crucial. The Extremes project, by taking natural science, sound, visuals, written words, interaction, curiosity, and diverse perceptions together, transcends the cognitive and elicits unspoken knowledge, leading to insights that feel deeper, are easier to relate to, and reach a wide audience.

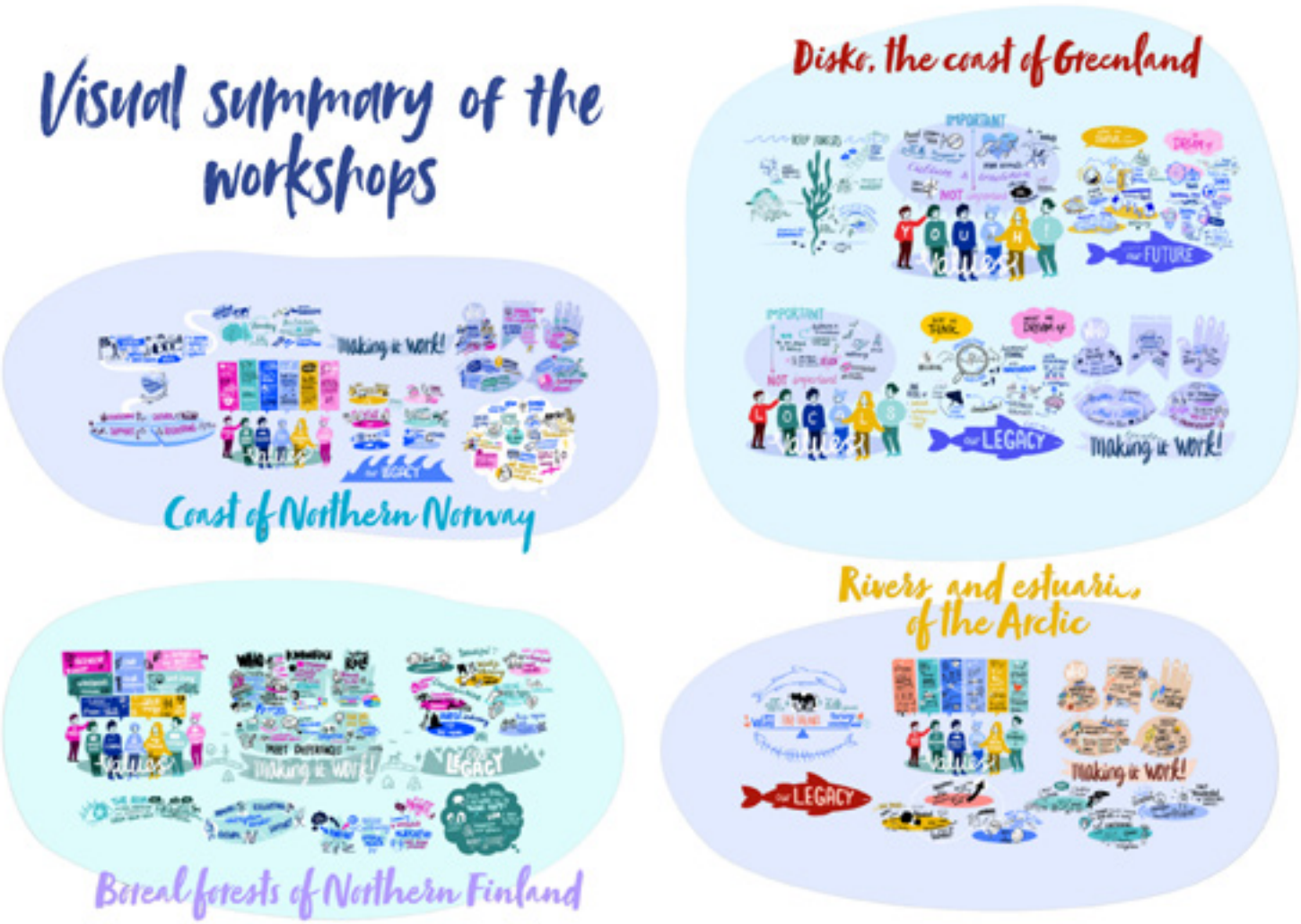
EXPLORE THE MIRACLE OF NATURE

In another project called GreenFeedBack, we travelled across the Nordics and Arctic to understand and visualise how ecosystem services intersect with our lives, choices, and knowledge, and how our worldviews and hopes for the future arise from our relationship with nature.

* An "imaginary" is the way in which a group or society perceives a certain phenomenon. Groups collectively shape imaginaries from myths, experiences, beliefs and narratives, as a way of understanding complex reality.


CULTURE, TRADITION & LIVELIHOOD
What nature provides us with is so closely intwined with culture. For many communities along the coast, what you harvest from nature is not only food, it also plays a key role in traditions, and creates important bonds between families, individuals and elders. It embodies people's symbolic ties to the environment and knowledge based on these environments throughout history.
-It is an identity, culture and lifestyle.
CO_2
interwined health
human values
FIND BALANCE
thriving nature
everything affects each other

Examples of visual summaries from our workshops dealing with coasts, rivers and estuaries. The key words were communication, openness, equality, justice, listening, common goals, compromise, understanding of diversity, a sense of belonging, ownership and creating a constructive loop between the different values in society, together with the wide range of people with unique knowledge, and making use of nature and what nature contributes.
Credits: Ann Eileen Lennert, Luca Berti, Nikki Schmidt, workshop participants, and the GreenFeedBack consortium



An exhibition was made based on the workshops done across the Arctic and connecting the insights with the natural science done within the project. Photography and scribing were used to create awareness and disseminate the knowledge and data. *Illustrations: Ann Eileen Lennert and Nikki Schmidt*

On the great expeditions of the 18th and 19th centuries, it was almost mandatory to bring a painter along to document the discoveries. Their paintings of natural phenomena, landscapes, and everyday environments were valued as artworks and regarded as part of the knowledge-gathering of the expeditions.

Frits Andersen, interviewed in the journal *Information*, 20 November 2025

We held creative workshops with youth and elders, students, researchers, local and Indigenous people, and administrators. Our motto: the more diverse, the merrier. Together, we shared and debated values, opportunities, challenges, priorities, and ethical ways to reach our goals. We listened, drew, and created spaces for being heard. Artistic tools fostered awareness and common ground across differing perceptions.

Having understanding of the diverse values, worldviews, perceptions and knowledge systems matters for management, policy and decision-making. We saw wide differences in connections to nature and views on its services: green energy was praised yet questioned; climate adaptation was deemed vital, but not at the cost of ecological balance. Ecosystem services must be read alongside social contexts, and local communities must be included and gain ownership in governance.

Everyone's knowledge is valuable–fisher, youth, Sámi, teacher, baker, you and me. Many workshop participants focused on provisioning services (which provide energy, food, medicine, materials and other things we need), noting how unsustainable use harms other ecosystem services. Stories described trawling impacting catchments across coasts, rivers, and lakes, affecting food security, cultures, and upstream livelihoods. Provisioning services were identified as being highly culture-specific: harvests feed bodies and traditions, bind families, and carry identity. Regulating and supporting services–often invisible, such as clean air–were seldom mentioned yet recognised as vital. In the GreenFeedBack project, art and research came together to illuminate their own value in guiding climate action, adaptation, and addressing the societal challenges we face today! ■

FURTHER READING:

Lennert AE, Berti L, Schmidt N, Bludd EC (2025) Art-based research can help us value nature in new ways. Opinion article in High North News, *https://www.highnorthnews.com/en/art-based-research-can-help-us-value-nature-new-ways*

Extremes Expedition 2025: *https://arcg.is/0G8rrD2*

GreenFeedBack: *https://eu-greenfeedback.com/*

A wild male Atlantic wolffish guarding an egg mass.
Photo: Erling Svensen, underwater photographer

Marianne Frantzen and Trude Borch // Akvaplan-niva
Camilla With Fagerli // Norwegian Institute for Water Research
Brian Tsuyoshi Takeda // Restorae
Øyvind Stråbø // Trefadder
Erling Natvig // Vår Energi

Can Atlantic wolffish help restore the kelp forest?

RESEARCH NOTES

Overfishing of species that prey on sea urchins has led to an ecological imbalance along the north Norwegian coast. Without these predators, sea urchins multiplied, turning once thriving kelp forests into vast “urchin barrens”. Restoring predatory Atlantic wolffish could be the key to reversing this loss.

A NATURAL SEA URCHIN PREDATOR

The Atlantic wolffish (*Anarhichas lupus*) is a relatively stationary bottom-dwelling species commonly found along the entire Norwegian coast, typically at depths shallower than 150 metres. It mainly feeds on sea urchins but is also partial to mussels, snails, and crabs. The species reaches sexual maturity at 6-7 years of age and it can live up to 25 years.

During the spawning season, male and female wolffish pair up and remain together at the spawning site until spawning. Unlike most other fish species, Atlantic wolffish has internal fertilisation. After the female lays her eggs, the male guards the egg mass for 9-10 months until hatching–a rare example of extended parental care among marine fish.

In captivity, natural mating behaviour does not occur, so artificial fertilisation techniques must be used. Females are briefly removed from the water, anaesthetised, and stripped of eggs, which are then fertilised with milt taken from males. The eggs are incubated in seawater tanks where they adhere naturally to one another as they develop.

RESTORING ECOLOGICAL BALANCE

Small-scale experiments have shown that removing sea urchins allows kelp to regrow quickly. But without continuous management, urchins rapidly recolonise and destroy the new growth. In other parts of the world, maintaining populations of sea urchin predators—fish, crabs, or lobsters—has proven vital for long-term kelp recovery.

Along the north Norwegian coast, areas where larger predators like the edible crab (*Cancer pagurus*) or king crab (*Paralithodes camtschaticus*) have become established (i.e. Nordland south of Lofoten and in some fjords in the north of Finnmark, respectively), we have seen sustained kelp regrowth. However, in much of the coastal areas of Troms and Finnmark, there are too few sea urchin predators such as wolffish, cod, haddock or large crabs to maintain this balance.

Given its feeding habits and adaptability to northern coastal environments, the wolffish appears to be a promising candidate for reintroducing natural "top-down" control of sea urchins. A restored kelp forest, in turn, would provide breeding and nursery habitat for cod, haddock, and many other species that depend on a healthy kelp ecosystem.

THE BLUE-REWILDING PROJECT

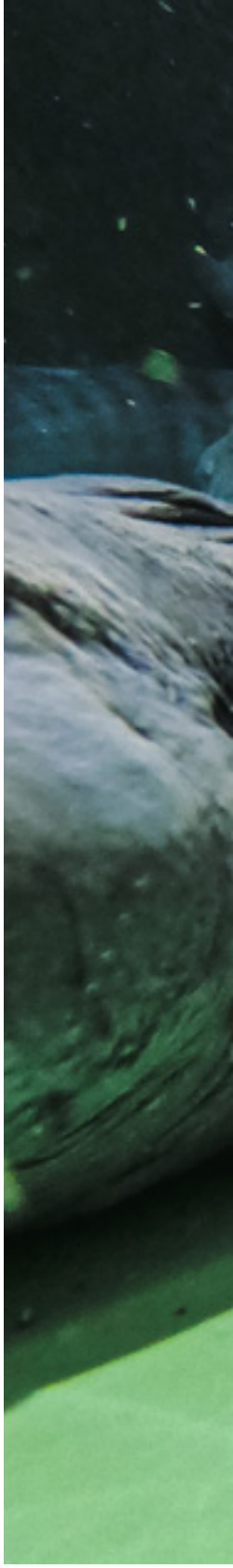
The BlueRewilding project—funded by Restorae and Trefadder/Vår Energi—aims to strengthen predator populations and promote lasting restoration of kelp forests in northern Norway. The project focuses on developing techniques to produce juvenile wolffish, including larval start feeding, juvenile growth monitoring, and adaptation to sea urchins as prey. The goal is to produce 500 release-ready fish for field trials.

In June 2025, Akvaplan-niva and NIVA collected 30 wild-caught Atlantic wolffish to serve as broodstock at Akvaplan-niva's research station outside Tromsø in northern Norway. Using experience from the long-standing research and breeding effort on spotted wolffish (*Anarhichas minor*) at Akvaplan-niva, researchers have successfully transitioned the wild-caught Atlantic wolffish from sea urchins to dry feed. The first female spawned on 10 December 2025, and during the following month the remaining females spawned. Fertilised eggs are now being incubated, and hatching is anticipated to take place in early summer 2026.

Beyond wolffish production, the BlueRewilding project will collect genetic samples from wild Atlantic wolffish populations in four to five fjord and coastal areas near Tromsø. These data will support future population management efforts. Applications for release permits are also being prepared, along with studies to determine the optimal release size, age, and frequency of wolffish releases needed for large-scale restoration.

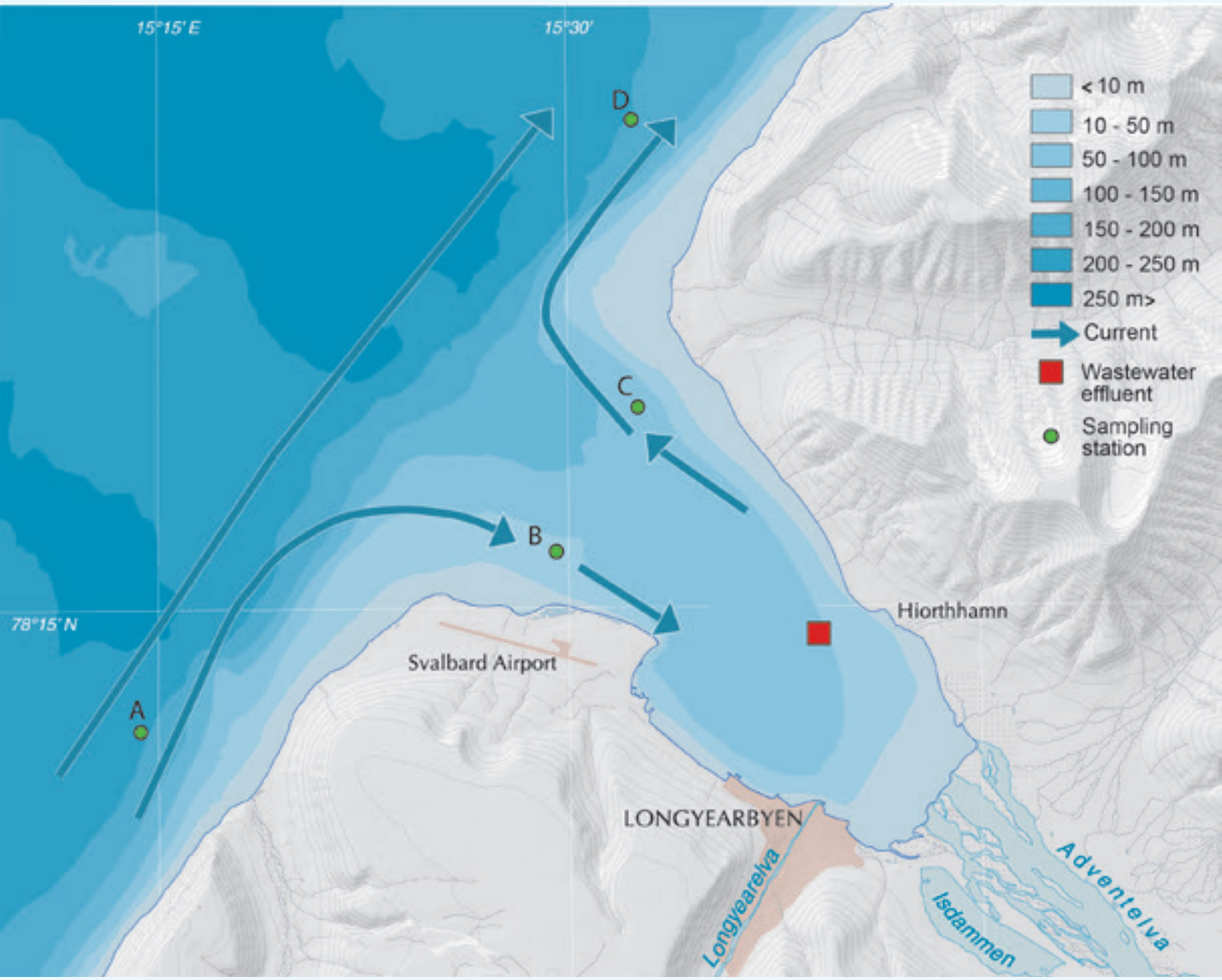
HEALTHIER COASTAL ECOSYSTEMS

By reintroducing the Atlantic wolffish as a key predator, the BlueRewilding project aims to restore ecological balance and resilience in kelp-dominated coastal ecosystems. Healthy kelp forests not only support marine biodiversity but also store carbon, reduce coastal erosion, and sustain valuable fisheries, making this effort an important step toward revitalising the underwater forests along the coast of Arctic Norway. ■



Some of the wild-caught Atlantic wolffish collected in June 2025 and kept for breeding at Akvaplan-niva's research station outside Tromsø. *Photo: David Gonzàlez Buendia / Buendia Media*

Stripping of the first spawning-ready female took place on 10 December 2025, and approximately 5000 eggs were fertilised before being placed into the egg incubator. *Photo: Terese Vollstad-Giæver / Akvaplan-niva*



Water sampling sites in and near Adventfjorden. A and B: sampling of inflow from Isfjorden; C: sampling near the wastewater effluent pipe; D sampling of outflow from Adventfjorden. *Map: Norwegian Polar Institute*

Carolin Philipp-Sørensen, Katrine Husum, Geir W Gabrielsen, Louise K Jensen and Ingeborg G Hallanger // Norwegian Polar Institute
France Collard // Norwegian Institute for Water Research
Claudia Halsband // Akvaplan-niva
Dorte Herzke // NILU
Giulia Vitale and Fabiana Corami // Institute of Polar Sciences, National Research Council of Italy (CNR-ISP)

Gone with the fjord? Dispersal of anthropogenic particles in Adventfjorden

RESEARCH NOTES

Wastewater from Svalbard's largest settlement, Longyearbyen, is released untreated into Adventfjorden through a pipeline. Denser anthropogenic particles settle near the outlet, while lighter particles disperse out of Adventfjorden and into Isfjorden. But how many particles, and where do they go?

A PREVIOUS SAMPLING EFFORT in 2017 showed that the number of manmade fibres in Longyearbyen's wastewater was similar to that in treated wastewater from large cities, such as Vancouver, Canada. The same study employed a modelling approach to forecast the distribution of fibres in the fjord. Four years later, we conducted a new field study to compare fibre numbers in surface water with the model outputs, and to investigate the dispersal dynamics of anthropogenic (manmade) particles in Adventfjorden *in situ* and ground truth the model results. The particles, such as plastics, were further categorised by shape into fibres and fragments. We expected to find the highest concentrations of human-introduced particles in Adventfjorden closest to the wastewater outlet and Longyearbyen itself.

In June 2021, we sampled surface water at four locations: two at the inflowing current from Isfjorden, one near the untreated wastewater outlet from Longyearbyen, and one in the outflowing current from Adventfjorden into Isfjorden. The samples were taken with a CTD-rosette equipped with 10-litre Niskin bottles collecting water in the first 10-100 cm from the surface.

We found that the inflowing current in Adventfjorden is already burdened with anthropogenic particles. What we did not expect was to have more than double the concentration, as well as twice as many types of anthropogenic particles at sites before the wastewater outlet compared to after. Potential sources of this pollution in Isfjorden include Barentsburg (another Svalbard

settlement), ship traffic in general (both tourism and shipping), as well as long-range atmospheric or oceanic transport from farther south.

So why did we not find a higher concentration of anthropogenic particles in Adventfjorden, where we expected to see local pollution in addition to particles from unknown sources, as predicted by the model? There are several possible explanations for these puzzling results. It is important to note that Longyearbyen and its wastewater system are known local pollution sources. The fact that we did not find higher concentrations close to the town, may be explained by the fact that we sampled only surface water and/or that the selected sampling sites in the fjord are affected by different oceanographic drivers. Our sampling campaign also provides only a snapshot of the particle burden. Good knowledge of how the water circulates in the fjord is essential to select a good sampling site. In Adventfjorden, we need to know how the circulation is affected by the seasonal rivers, especially the large Advent River, as well as whether sea water is driven by tides or by background circulation impacting the mixing of the water column. Others have pointed out that river plumes push anthropogenic particles ahead of them, effectively ploughing the surface water clear of such materials. We also know that due to density differences some particles will sink below the freshwater layer. The local pollution will also fluctuate by the time of day and the day of the week, corresponding to human activity levels.

For future sampling to quantify and monitor local pollution it is very important to be able to measure the local pollution, and to differentiate between local and long-distance sources. To get reliable data on local pollution from sea water it is vital to know the circulation pattern on a seasonal scale as well as the influence of river run-off for the site in question.

To conclude, Longyearbyen is a local source of anthropogenic pollution in Svalbard, though it is hard to put a number on the magnitude due to changes during the day and along seasons. In the future, ecotoxicologists and oceanographers need to cooperate on robust sampling strategies to gain better knowledge and monitor local pollution. ■

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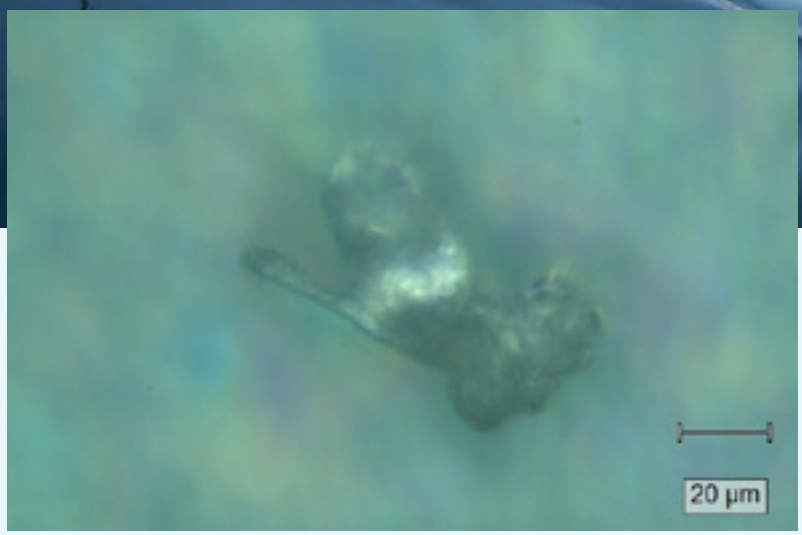
Herzke D, Ghaffari P, Sundet JH, Tranang CA, Halsband C (2021) Microplastic fiber emissions from wastewater effluents: abundance, transport behavior and exposure risk for biota in an arctic fjord. Frontiers in Environmental Science 9: 662168, *https://doi.org/10.3389/fenvs.2021.662168*

Philipp C, Collard F, Halsband C, Herzke D, Vitale G, Corami F, Husum K, Gabrielsen GW, Hallanger IG (2026) Microplastic and other anthropogenic particles in surface waters of the Isfjorden system (Svalbard). Environmental Pollution 390: 127563, *https://doi.org/10.1016/j.envpol.2025.127563*

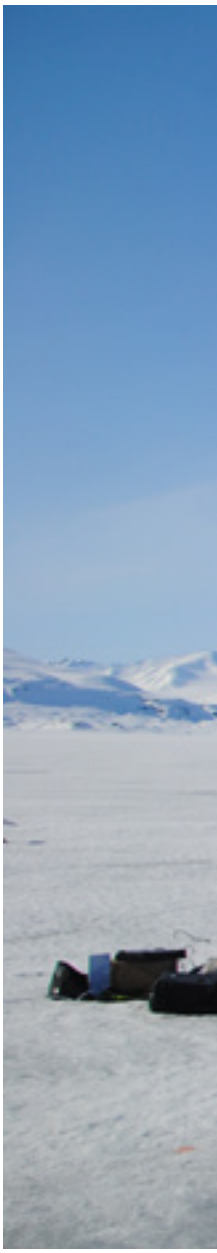
Neuston catamaran at sampling site A, with Adventdalen in the background. *Photo: Trine Lise Sviggum Helgerud / Norwegian Polar Institute*

Tapping sampled surface water from the CTD array in the hangar on board RV *Kronprins Haakon*. *Photo: Ann Kristin Balto / Norwegian Polar Institute*



Example of a polypropylene particle. *Photo: Carolin Philipp-Sørensen / Norwegian Polar Institute*

Andy Lowther, Kit M Kovacs and Christian Lydersen // Norwegian Polar Institute
Rolf A Ims // UiT The Arctic University of Norway
Marc Rams i Rios // Marine Mammal Institute, Oregon State University, USA
Alberto Roldan Sastre // University of Akureyri, Iceland



Use of drones and AI for monitoring ringed seal abundance in Svalbard

RESEARCH NOTES

Tracking changes in the abundance of Arctic species has historically been tedious and exacting work. Now modern technology is being put to use to facilitate this important task.

Monitoring Arctic sentinel species, such as marine mammals, typically involves regular assessments of population size, which are often conducted by counting individuals from images collected during aircraft surveys. In Svalbard, the most recent aerial survey of ringed seals was conducted almost two decades ago using a fixed wing (piloted) aircraft to collect photographic imagery across 18 fjords throughout the archipelago. This survey generated over 20,000 images, all of which had to be processed manually. Collecting and analysing aerial imagery requires significant manpower (and hence financing) to process large volumes of raw images into data, extracting the needed information on a timescale useful for management purposes.

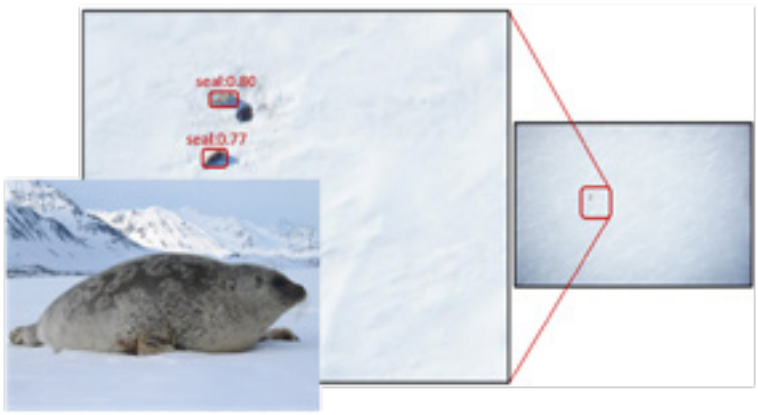
The pressing need for rapid analysis of large imagery datasets has driven recent advances in the use of Computer Vision (CV) models. One-stage or optimised CV models have emerged as powerful tools for reducing the workload associated with processing aerial imagery in animal surveying. Over the past five years, the Norwegian Polar Institute has been developing the techniques, methodologies and field competence to survey marine mammals using drones. Between 2023 and 2025, full-scale surveys of ringed seals hauled out on all ice-covered areas in Isfjorden (2023, 2024, 2025), Van Mijenfjorden (2024, 2025) and Kongsfjorden (2024) were conducted, resulting in the first updated abundance estimate in twenty years (see Further reading). Over 32,000 aerial

Drones were Vertical Take-Off and Landing (VTOL) capable, enabling controlled vertical launch and recovery from sea ice or small areas of beach, while a more energy-efficient fixed wing flight mode maximised survey coverage. *Photo: Marc Rams i Rios / Oregon State University*

Between each hour-long survey flight, the lithium ion batteries and camera memory cards were replaced, and the drone was back in the air within minutes. *Photo: Kit Kovacs / Norwegian Polar Institute*

Downdrafts during landing meant that the camera had to be cleaned of snow prior to each flight. The airframe was light enough to make this task easy. *Photo: Christian Lydersen / Norwegian Polar Institute*

Mission planning required high resolution maps against which to plan flights. Starlink connectivity coupled with laptops connected to drone flight controllers enabled a streamlined data collection pipeline from flight planning through to image collation. All images were georeferenced to <1 cm accuracy using Post Processing Kinematics. *Photo: Marc Rams i Rios / Oregon State University*



Clear, blur-free images resulted in a high quality dataset which could be annotated for the presence of ringed seals. This dataset was used to train our Computer Vision model which achieved high classification success when exposed to new images (in this case 80% and 77% accuracy at correctly identifying seals). *Photos: Christian Lydersen / Norwegian Polar Institute and Alberto Roldan Sastre / University of Akureyri*

The relatively large airframe of the drone coupled with fixed-wing flight mode provided greater stability over the survey area, reducing image blurring. *Photo: Christian Lydersen / Norwegian Polar Institute*

images were collected and used to train and validate a state-of-the-art optimised CV model to streamline image processing.

We used a single-stage CV model called YOLO8, trained on a large subset (70%) of the manually annotated survey imagery collected in Isfjorden. The remaining images from the Isfjorden surveys were used to evaluate and adjust the model in order to determine whether it is generalising well or merely memorising the training data. After refining the training process over several iterations, we finally tested the model on a test set consisting of the Van Mijenfjorden survey imagery.

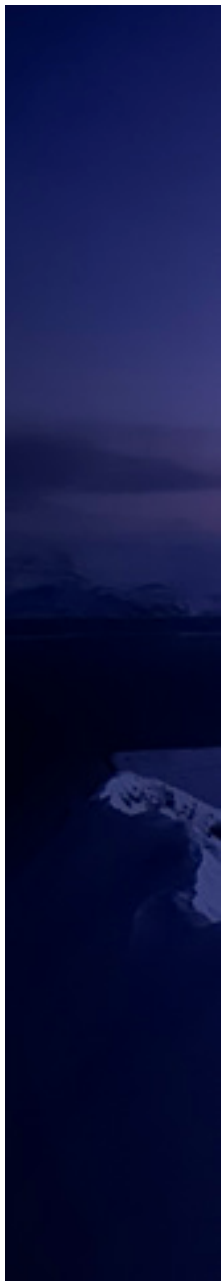
The final model detected 96% of the seals in the Van Mijenfjorden test dataset and reduced the human workload for post-processing image analyses by 99.7%.

From an ecological perspective, the combined ringed seal survey studies that we have undertaken in the last three years show a significant decline (circa 50%) in ringed seal abundance over the last two decades in Kongsfjorden, Van Mijenfjorden and Isfjorden. The interannual variability in abundance observed across fjords during this study underscores the importance of monitoring over several years to determine reasonable abundance estimates and understand variance. Given the analysis pipeline established, expanding this approach to estimating harbour seal and walrus abundance in Svalbard is tractable. The model developed in the ringed seals studies will be retrained on appropriate annotated species-specific aerial imagery. Overall, our research demonstrates an efficient, cost-effective pipeline for obtaining rapid and reliable abundance data for seals in future monitoring surveys and offers insights into the ringed seal's status and distribution in western Svalbard. ■

FURTHER READING:

Rios MRI, Kovacs KM, Lydersen C, Ims RA, Lowther A (2025) Ringed Seal (*Pusa hispida*) Abundance in Isfjorden, Svalbard, After 20-Years of Climate Change and a Concomitant Survey Hiatus. Marine Mammal Science 42(1): e70076, *https://doi.org/10.1111/mms.70076*

Sastre A (2025) The Fjords of the Ringed Seal: Assessing the Status of Ringed Seals in Western Svalbard through Machine Learning. Thesis for Masters degree, University of Akureyri, Iceland. *https://skemman.is/bitstream/1946/51576/1/CMM_Alberto_Rold%C3%A1n_Sastre_MSc_thesis.pdf*



Allison Bailey, Philipp Assmy, Anette Wold, Fanny Cusset, Igor Eulaers, Agneta Fransson, Lucie Goraguer, Marianna Pinzone and Mats Granskog // Norwegian Polar Institute
Daniel Vogedes, Roberta Cardenas and Ricarda Runte // UiT The Arctic University of Norway
Malin Daase* // University Centre in Svalbard
Clara JM Hoppe, Sneha Sivaram and Max Willems // Alfred Wegener Institute, Germany
Catarina Magalhaes and Eva Lopes // Interdisciplinary Centre of Marine and Environmental Research, Portugal
Slawomir Kwasniewski, Józef Wiktor, Agnieszka Tatarek, Marta Gluchowska and Monika Zablocka // Institute of Oceanology Polish Academy of Sciences
Melissa Chierici // Institute of Marine Research
Milan Beck // University of Bremen, Germany
Lola Nader // University of Kiel, Germany
Anand Jain and Divya David T // National Centre for Polar and Ocean Research, India
Roberta Guerra // University of Bologna, Italy
Carmen Rizzo // Stazione Zoologica Anton Dohrn, Italy
JP Balmonte // Lehigh University, USA
Manuel Bensi // National Institute of Oceanography and Applied Geophysics, Italy
Francesco Paladini de Mendoza // Institute of Polar Science, Italian National Research Council

Year-round monitoring of the marine ecosystem in Kongsfjorden

RESEARCH NOTES

For a few short weeks each year, the Arctic appears to burst into life. Early explorers often marvelled at the contrast between the silent, dark winter months and the sudden, shimmering activity under the summer midnight sun. This dramatic flip traces back to the poles' extreme annual light cycle—and it shapes not only the ecosystem but also the rhythms of Arctic research itself.

* Also affiliated with UiT The Arctic University of Norway

Kongsfjorden as seen from Ny-Ålesund Research Station's Zeppelin Observatory atop Zeppelin Mountain. The faint light in the inner fjord is from Kings Bay's research boat, MV *Teisten*, conducting the January transect. *Photo: Ceslav Czyz / Norwegian Polar Institute*

Because summer brings 24-hour sunlight, the mildest weather, the most open water, and the least sea ice, it is also the season we know best. Much of what scientists understand about the Arctic seas comes from this narrow window, when ships can travel farthest and safest. For decades, researchers assumed that the Arctic ecosystem mirrored this pattern: lively and productive in summer, dormant and quiet in winter.

But a few rare—and logistically demanding—winter campaigns have upended that view. They show that many organisms remain active throughout the polar night, that key life-history events unfold outside the summer season, and that unexpected biological activity can occur even in the dark. If we focus our research only on summer, we risk overlooking these crucial dynamics, including climate-sensitive stages and processes that take

Pulling up a plankton net in the dim light of January in Kongsfjorden in -21°C. For winter work at sea, the researchers were joined by two members of the Kings Bay crew for added safety. The winch aboard the MV *Teisten* is key to utilising many heavy marine sampling instruments. *Photo: Allison Bailey / Norwegian Polar Institute*

place in fall, winter, and spring. To understand how the Arctic is responding to rapid warming, we need a year-round baseline—otherwise, small shifts in timing of key ecological events (a documented impact of climate change) could be misread, or worse, overlooked.

Yet, monitoring Arctic marine ecosystems across all seasons is notoriously difficult. Reliable access is limited: in Svalbard, for example, no large research vessels are stationed year-round, and only a single small research vessel operates throughout the year. Autonomous oceanographic moorings—underwater observatories anchored to the seafloor—help bridge the gap by collecting data in all seasons without human presence. But they are limited to a few locations and can measure only what their sensors are built for, such as temperature, salinity, currents, or acoustic signals of fish biomass. And many disregard the upper 20 metres of the water column to avoid interference with ships and ice, although that is exactly where some of the most dynamic biological processes occur.

To bring researchers themselves into the winter environment, several ambitious expeditions have frozen large research vessels into the drifting pack ice, turning them into mobile bases for months at a time. These drifting stations provide shelter, laboratories, and access to the surrounding ocean—but because they move with the ice, they pass over contrasting water masses and a shifting mosaic of habitats rather than staying anchored to one pelagic ecosystem through the year.

The ideal scenario, then, is simple but challenging: study a single Arctic marine habitat continuously year-round.

In Svalbard's Ny-Ålesund Research Station, situated on the banks of Kongsfjorden, this becomes possible. With a research boat available year-round, on-site housing and laboratory facilities, biweekly flights even in winter, and an active international scientific community, the station is uniquely positioned to host coordinated seasonal studies of a high Arctic marine ecosystem. Recognising this potential, researchers within the Ny-Ålesund Kongsfjorden System Flagship—a

When the sun returns to Kongsfjorden, it has implications across the system, from phytoplankton to pollutant cycling. This photo was taken during a sampling transect along Kongsfjorden February 24–26, about a week after the return of the sun. *Photo: Anette Wold / Norwegian Polar Institute*

Sea ice threatened to block the exit of MV *Teisten* from the harbour in May. *Photo: Allison Bailey / Norwegian Polar Institute*

Apherusa is an unmanned surface vehicle (USV) belonging to UiT The Arctic University of Norway. The USV conducted four seasonal hydroacoustic surveys in Kongsfjorden during the International Kongsfjorden Year. *Photo: Malin Daase / UiT The Arctic University of Norway and University Centre in Svalbard*

Midwinter darkness. Scientists from India's National Centre for Polar and Ocean Research collecting water samples and taking CTD measurements in the polar night during the International Kongsfjorden Year. *Photo: Emelia J Chamberlain / Wood Hole Oceanographic Institution*

A beautiful evening to deploy an ocean observatory in Kongsfjorden. Doing fieldwork in the Arctic in late summer is traditional for a reason: minimal sea ice, 24-hour daylight and more frequent stable weather patterns make for easier logistics. *Photo: Malin Daase / UiT The Arctic University of Norway and University Centre in Svalbard*

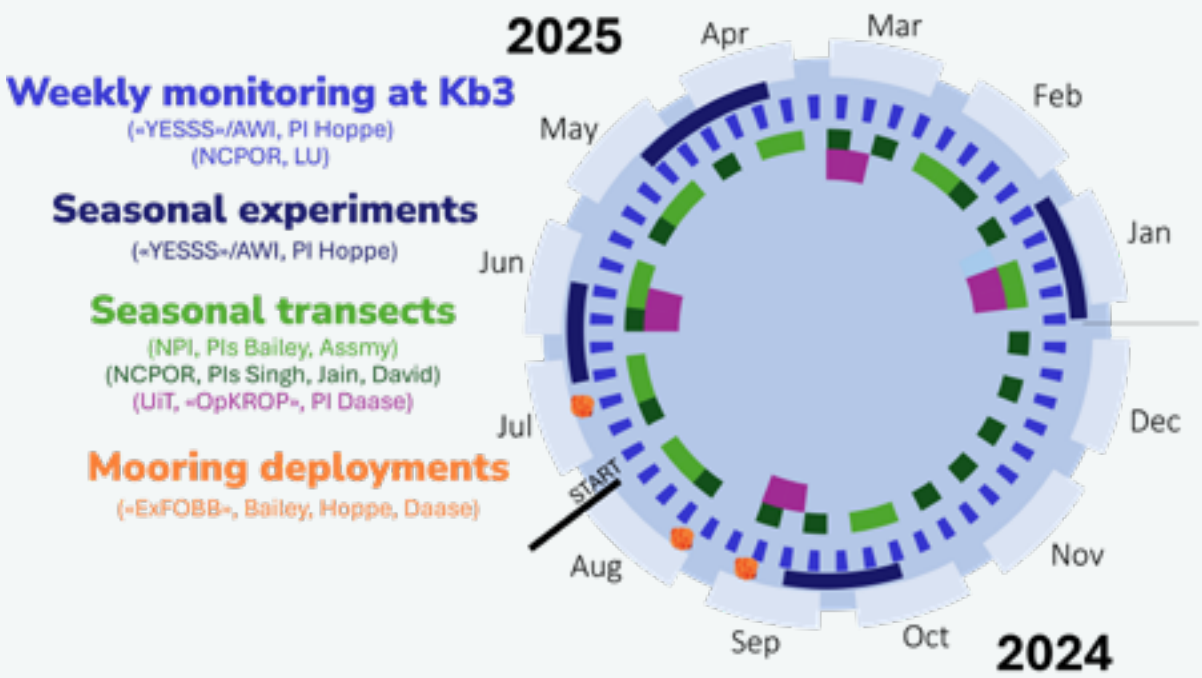
collaborative marine research network–developed a year-round campaign now known as the International Kongsfjorden Year (IKY).

Over several years of discussions at annual Flagship meetings, the outlines of the campaign took shape. Multiple proposals were submitted to national and international funding sources, and teams from a growing list of countries committed to participating.

The largest project under the IKY umbrella was the German YESSS project, led by Clara Hoppe. YESSS stationed two rotating research teams in Ny-Ålesund for an entire year, gathering weekly measurements at both a deep mid-fjord pelagic site and an intertidal site, together with collaborators from India and the United States. Alongside high-frequency, year-round monitoring of plankton, protists, microbes and biogeochemical parameters, the project examined how seasonal conditions influence the sensitivity of four key organismal groups–polar cod, sea urchins, kelp, and phytoplankton–to ocean warming.

To complement these detailed observations at the central fjord site, additional teams collected data on similar parameters along the full length of the fjord. These efforts explored how signals observed at the central site vary spatially and how processes such as glacial meltwater inputs and inflowing Atlantic currents shape the ecosystem throughout the year. These included Norway's OpKROP project, led by Malin Daase, which conducted four seasonal surveys along spatial transects, including optical properties and hydroacoustics to complement their long-term Kongsfjorden Marine Observatory programme; the Norwegian Polar Institute's eight seasonal transects; and India's bi-monthly CTD surveys.

Nine Arctic Field Grant recipients added further layers of insight, contributing new parameters, sampling capacity, and international collaboration. Cooperation among project groups was extensive: teams collected samples for one another, shared equipment, hosted collaborators on their vessels, and exchanged near-real-time information on conditions in the fjord.



The annual wheel of key sampling campaigns during the International Kongsfjorden Year. The figure does not show all of the projects or ongoing time series that are included in the IKY initiative. *Figure: Allison Bailey / Norwegian Polar Institute*

Meanwhile, the project ExFOBB (Extending Fjord Observatories for Biogeochemistry and Biology) funded by the Svalbard Integrated Arctic Observing System (SIOS) deployed three additional moorings in Kongsfjorden during the IKY period: a profiling mooring to capture surface-layer dynamics that traditional moorings often miss, and two inflow moorings placed to detect Atlantic Water before it enters the fjord.

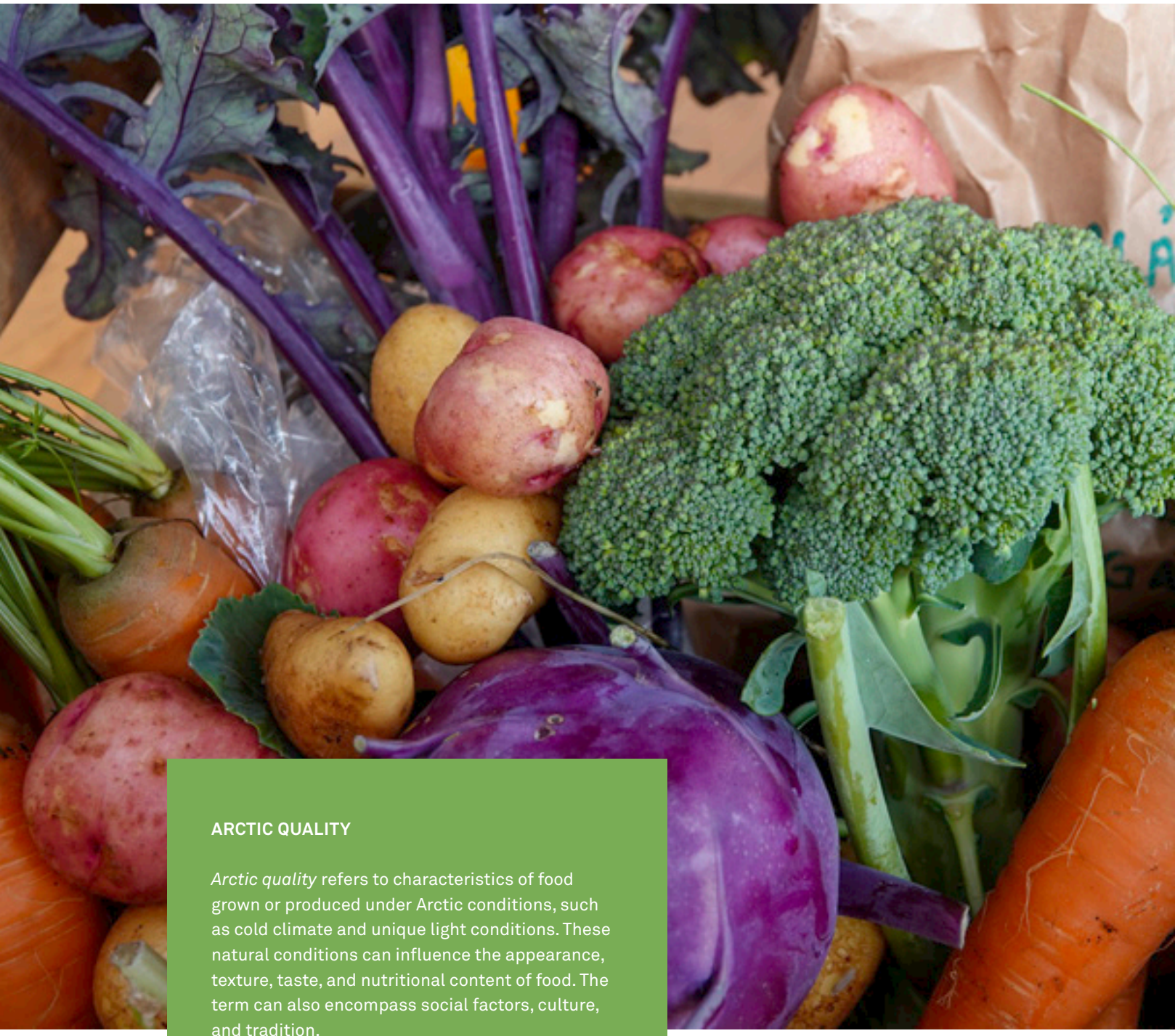
Together, these efforts created a year unlike any other. In 2024-2025, the marine ecosystem of Kongsfjorden was observed with unprecedented temporal resolution, capturing the full seasonal rhythm of one of the Arctic's most intensively studied fjords. The next phase is underway: analysing these immense datasets and synthesising them into ecosystem-level understanding. This work will lead to broad Flagship-led syntheses and a suite of more focused, project-level publications that will help define key periods for future monitoring and deepen our understanding of how Arctic ecosystems function–and change–across the entire year. ■

FURTHER READING:

About IKY:
https://nyalesundresearch.no/2024/06/the-international-kongsfjorden-year-2024-2025/

About the YESSS project:
https://yesss.science/

About OpKROP:
https://www.mare-incognitum.no/opkrop/



ARCTIC QUALITY

Arctic quality refers to characteristics of food grown or produced under Arctic conditions, such as cold climate and unique light conditions. These natural conditions can influence the appearance, texture, taste, and nutritional content of food. The term can also encompass social factors, culture, and tradition.

(Definition of *Arctic quality* in the survey)

The project is funded through the initiative "Sustainable Food Production and Value Creation in the North", managed by the county municipalities of northern Norway.

Some of the vegetables that do well under the midnight sun, earning the right to be called *Arctic quality*. *Photo: Morten Günther / NIBIO*

Jon Schärer // Norwegian Institute of Bioeconomy Research

Arctic quality – What do consumers think?

SCIENCE AND SOCIETY

What does “Arctic quality” mean for Norwegians? A survey of over 1400 consumers shows that the term itself is little known, but that most people view northern Norwegian food and agriculture positively, primarily because local farming supports local value creation, culture, and natural qualities.

As part of efforts to strengthen agriculture in northern Norway, the term *Arctic quality* can be developed and used as a competitive advantage.

“To utilise this potential, it is important to understand how consumers perceive *Arctic quality*,” says researcher Frøydis Gillund at the Norwegian Institute of Bioeconomy Research (NIBIO). She leads a project aimed precisely at finding out.

The unique conditions in the north, with low temperatures and exceptional light conditions, affect appearance, taste, and nutritional content, especially in plants.

Many sheep raised in northern Norway live in stunning natural surroundings.
Photo: Morten Günther / NIBIO

"This makes vegetables and berries grown in the north often sweeter and with a crisper texture than those grown further south. This has been documented for carrots, swedes, broccoli and strawberries–and these are precisely the features we call *Arctic quality*," says Gillund.

ARCTIC QUALITY

NIBIO has previously examined and documented how natural and climatic conditions influence traits such as taste, texture, and bioactive compound content in products from northern Norwegian farms, forests, and meadows, especially vegetables and berries. Now, consumer opinions and perceptions are in focus, and together with colleagues Atle Wehn Hegnes and Geir Wæhler Gustavsen, Gillund has taken a broad approach.

"We started by investigating how the term *Arctic quality* is described in Norwegian and international research literature, and what the literature says about how consumers understand this concept," says Atle Wehn Hegnes, who emphasises that they have not systematically reviewed all research in the field, as that is beyond the scope of the project. Nevertheless, the study gives a clear impression that *Arctic quality* as a concept in relation to food in Norway is little known.

"Terms like northern Norwegian food, food from northern Norway, or Arctic food seem to be more widely used," says Hegnes.

As part of the project, northern Norwegian stakeholders from different parts of the food value chain were also invited to focus group interviews. This included producers, restaurants, producer networks, processing companies, sales channels, and regional support actors. Together with the literature review, these discussions formed the basis for topics and questions for the consumer survey.

CONSUMERS SPEAK

The results of the survey show that most people do not know the term *Arctic quality*–not even those living in northern Norway.

"But when the term is explained for them, they have strong positive associations," says research professor Geir Wæhler Gustavsen. "They think of purity, naturalness, local roots, cultural heritage (including Sami traditions), and environmental values. Many see *Arctic quality* as more than just 'food from northern Norway'–it gives a sense of something exclusive and unique."

"The survey clearly shows that *Arctic quality* is still a relatively unknown concept for most people," emphasises Gustavsen. "Only 28% of respondents have heard of or are familiar with the term. In northern Norway, awareness is somewhat higher, but even there, only 43% had heard of or knew the term. This means that over half of northern Norwegians have no connection to *Arctic quality* as a concept."

WHERE IS THE BOUNDARY?

But where is the boundary for what can be called *Arctic quality*? Consumers disagree: 46% believe that only food produced north of the Arctic Circle can be called *Arctic quality*; 33% believe food from all of northern Norway is included. Only 3% think all food produced in Norway can be called *Arctic quality*.

In northern Norway, more people think the Arctic Circle is the limit, but even here many include the entire region. Scientific research has documented that some northern products have distinct qualities that affect taste.

Strawberries grown in the High North are uncommonly aromatic. *Photo: Morten Günther / NIBIO*

Frøydis Gillund picking bilberries with *Arctic quality*. *Photo: Private*

SELECTED RESULTS:

- Of the 1460 survey participants, 407 were familiar with the term "Arctic quality," corresponding to 28%, while 72% were not familiar with the term.
- Of those living in Nordland, Troms, or Finnmark, 43% knew the term.
- Among several alternative values, "Purity and naturalness" was most commonly associated with Arctic quality (64% overall and 74% of those living in northern Norway).
- "Local roots" was the second most commonly associated value (54%).

SELECTED STATEMENTS:

- Arctic food tastes better than other similar food: 34% of the total sample completely or partially agree. Among northern Norwegians, 55% agree, and 61% of those familiar with Arctic quality agree.
- Arctic food is more nutritious than other similar food: 25% completely or partially agree.
- Arctic food is more natural than other similar food: 43% completely or partially agree. Among northern Norwegians, 60% agree, and 65% of those familiar with Arctic quality agree.
- Arctic food is too expensive compared to other similar food: 39% completely or partially agree. Among northern Norwegians, 51% agree, and among those familiar with Arctic quality, 50% agree.

WILLINGNESS TO PAY MORE:

- Carrots: 27% of the total sample are willing to pay more; 50% of northern Norwegians; 44% of those familiar with Arctic quality.
- **Potatoes:** 25% total; 47% northern Norwegians; 40% familiar with Arctic quality.
- **Strawberries:** 31% total; 57% northern Norwegians; 50% familiar with Arctic quality.
- **Lamb:** 33% total; 51% northern Norwegians; 51% familiar with Arctic quality.

"It is also interesting to note that 34% of respondents completely or partially agree that Arctic food tastes better than other similar food. Among northern Norwegians, the number is even higher, with 55% agreeing," says Gustavsen.

ARCTIC AGRICULTURE AND PREPAREDNESS

Both climate change and international events have increased attention to food security and self-sufficiency nationally and regionally. In this perspective, northern Norwegian production may gain increased strategic significance, the researchers point out. Northern Norway is strategically important for national security. Long distances, scattered settlements, and challenging climatic conditions make supply lines in the region vulnerable. Therefore, maintaining food production in the north is crucial. *Arctic quality* can thus be linked to preparedness and self-sufficiency–not just taste and identity.

"But for the term *Arctic quality* itself to gain traction, it must be filled with credible content, documented, and communicated in a way that makes sense for both producers and consumers," says Atle Wehn Hegnes.

A field of *Arctic quality* potatoes growing just minutes from the centre of Tromsø. *Photo: Morten Günther / NIBIO*

TRUST IS CRUCIAL

Frøydis Gillund believes it is important to take seriously that some respondents expressed scepticism about whether the term really says anything about product quality. For example, some think the label is a marketing trick or a fancy name aimed at tourists and international markets.

"Discussions in the workshop also showed that many prefer terms like 'northern Norwegian' or 'local' food when interacting with local customers and in the grocery market. This is because it is more recognisable among consumers.

"Trust is crucial," emphasises Gillund, who remains optimistic based on the project and survey.

"With clear documentation, communication, and collaboration, *Arctic quality* has the potential to become a competitive advantage for agriculture in the north. It can also contribute to increased pride, value creation, and sustainability in the region," says the NIBIO researcher who led the project on consumer understanding of *Arctic quality*. ■

Anne Guro Nøkleby, Carl William Lund and Ole Magnus Grønli // Norwegian Mapping Authority

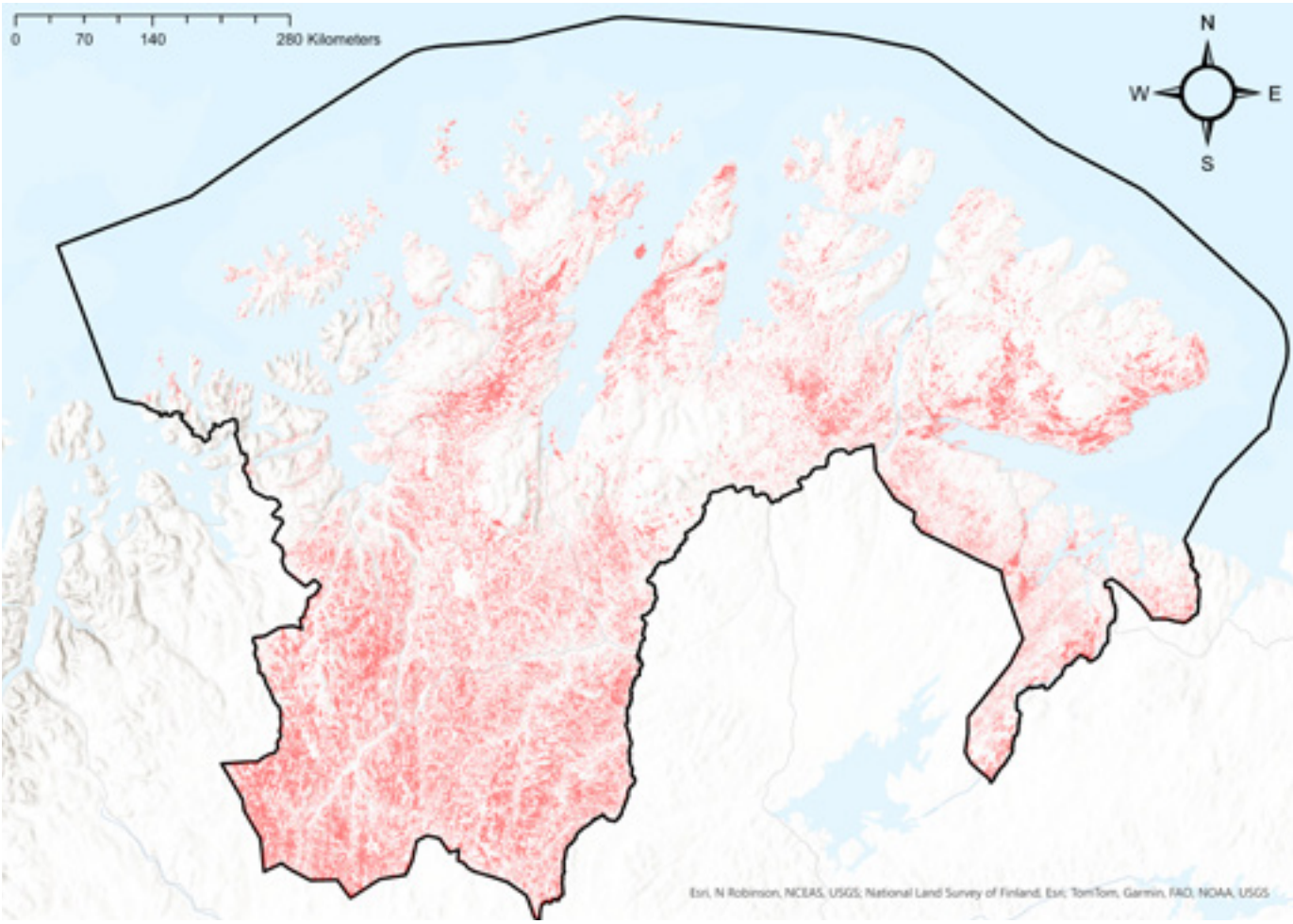
LAVDAS: Advancing nationwide wetland mapping

RESEARCH NOTES

State-of-the-art technology is providing a far more precise picture of Norway's wetlands. The LAVDAS project is testing new mapping methods to reveal the location of Norway's peat bogs and fens.

Norwegians typically think of their bogs and fens as places with squishy trails, challenging ground underfoot and a characteristic odour of slow decomposition. And many probably associate them mainly with the rare edible cloudberries known as "Arctic Gold". Yet the cloudberry's native habitats also rank among Norway's most valuable natural resources. Peatlands, also known as mires, bogs and fens, store large amounts of carbon, purify water, and provide habitats that support biodiversity. The total economic value of this ecosystem is estimated to several billion Norwegian Kroner annually.

A few years ago, Norway obtained its first reliable statistical overview of the likely scale of its wetlands, but their exact locations are yet to be determined nationwide. The original map data has gaps, with large areas–especially those above the treeline–lacking updated data. **LAVDAS**, which stands for *Landsdekkende våtmarksdatasett* ("Nationwide Wetlands Geospatial Dataset"), will help close the knowledge gaps by using deep neural networks (AI) to identify and delineate wetlands throughout Norway.



Overview of wetlands in Finnmark based on LAVDAS results.
Map: Carl William Lund / Norwegian Mapping Authority

FROM AIMS TO RESULTS

LAVDAS aims to improve the national map data on Norway's wetlands. To achieve this, the project is analysing large volumes of geographical data. The main data sources are satellite images revealing colours and vegetation, and elevation data representing landscape features. The combined data makes it possible to identify patterns typical of different land forms such as wetlands.

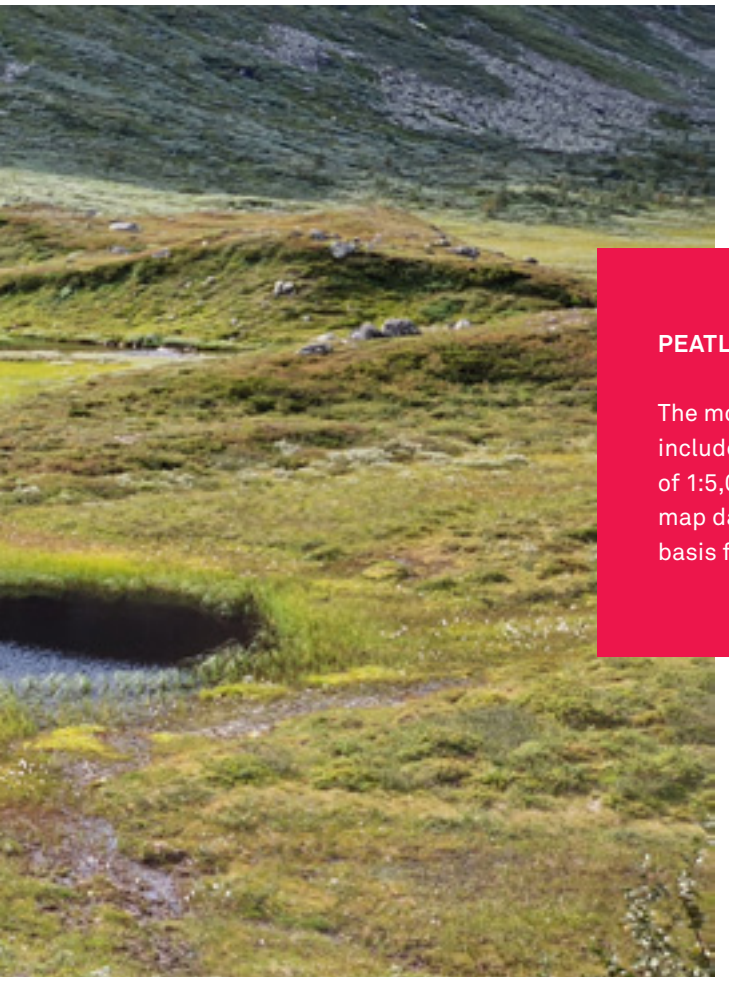
Developing an AI model viable for all parts of Norway is a demanding process. The extreme variations in terrain, climate and the seasons affect the appearance of wetlands as seen from satellites in various ways across the country. LAVDAS has consequently developed a range of models, each of which addresses different challenges. The initial model was based on previous research by the Norwegian Institute for Nature Research. The Norwegian Computing Center augmented this model with the aid of extensive training data and by adjusting the parameters. The Google AlphaEarth model with its embedding technology has been tested, and a Foundation Model developed for Climate and Society (FM4CS) has been trialled to understand and analyse the terrestrial surface.

PROBABILITY MAP YIELDS NEW INSIGHTS

The latest model, a composite of the different models based on an optimised weighting, has yielded promising results rendered as a precise "probability map". When tested against data from sampling areas evenly spread throughout Norway, contained in a dataset maintained by the Norwegian Institute of Bioeconomy Research, the probability map identified 97.6% of pre-classified pixels correctly. If we then compare the LAVDAS results with the established Land Resource Map (AR5) and the national topographic map dataset of Norway (N50) the estimates of Norwegian peatland cover are very different.

In Finnmark County, for example, detailed data are only available for small areas. The Norwegian Mapping Authority's national N50 map estimates that around 5% of Finnmark consists of peatland. Meanwhile, AR5, the Norwegian National Land Resource Map shows less peatland cover in Finnmark at only 0.8%. The LAVDAS model, however, shows 12.8% cover, yet also identifies much of the peatland classified in both N50 and AR5. This suggests that current maps provide an inadequate picture of Norwegian wetlands, especially in mountainous regions and in areas such as Finnmark.

Another important task is to set clear threshold values for the probability maps. This includes determining when an area should be classified as peatland and when it should be marked as indeterminate. The task provides valuable experience that can later be applied in mapping other landforms.



A typical peat bog in Vang Municipality.
Photo: Arvid Lillethun / Norwegian Mapping Authority

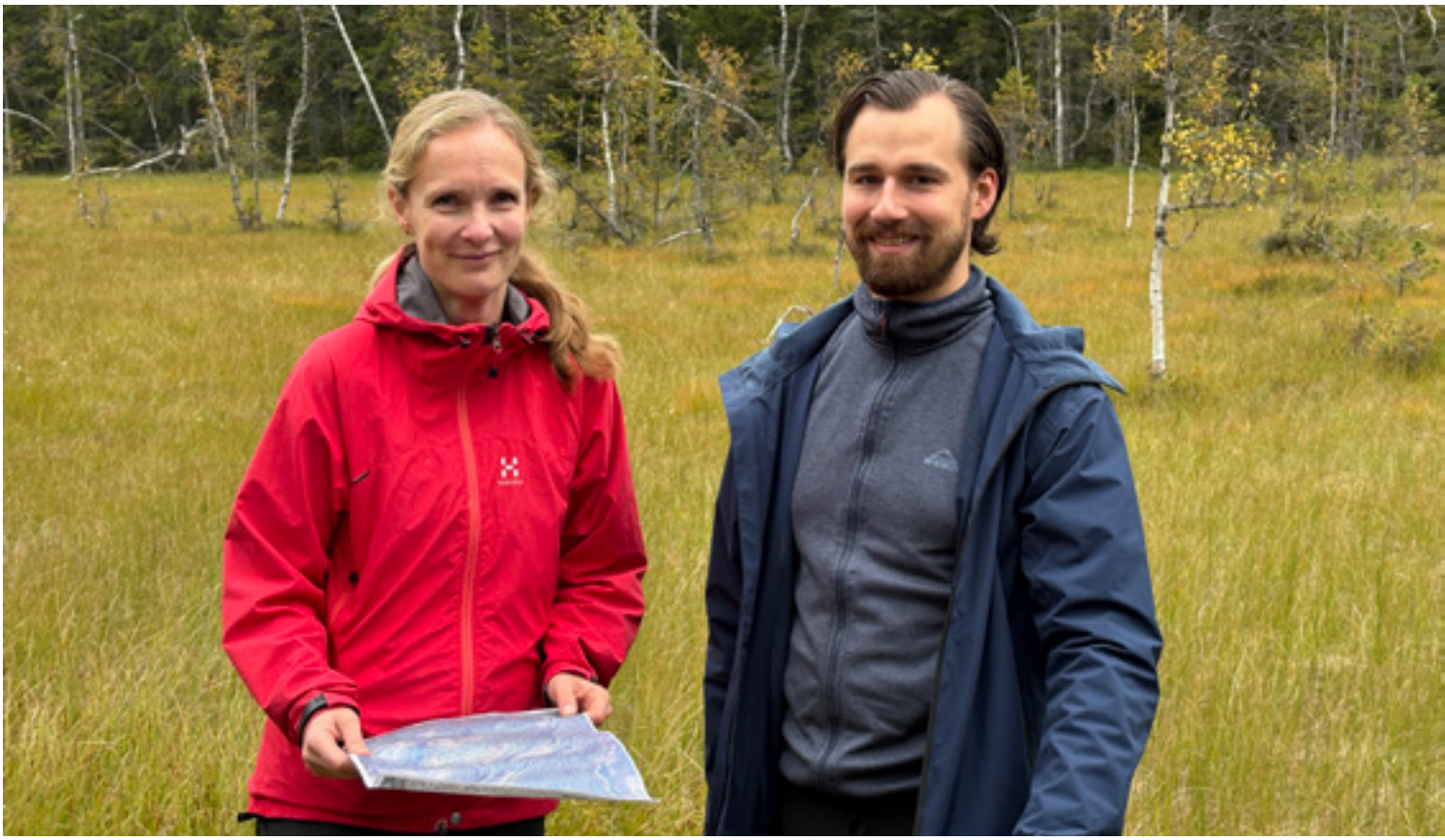
PEATLAND MAP DATA

The most important map data on peatlands is included in the ARS land resource map at a scale of 1:5,000. Beyond the AR5 coverage area, the N50 map data is the most viable source, and forms the basis for the national Norway 1:50,000 map series.

BETTER MAPS—BETTER DECISIONS

One of the aims of LAVDAS is to make information about Norway's wetlands, including peatlands, more accessible for natural resource management. To that end, the project started with a wide-ranging survey of user needs. As the project progresses, ongoing dialogue with users will ensure that the data can be used for countryside management, climate action, land use planning and biodiversity conservation. The maps will be made available through Geonorge, the Norwegian national website for map data and other location information. Geonorge and the other joint solutions will be developed over the next few years towards a new collaboration platform, which will hopefully include access to the improved wetland data.

The prospect of a national ban on peatland degradation makes this project even more timely. The Ministry of Climate and Environment and the Ministry of Local Government and Regional Development are proposing incorporation of a prohibition against peatland degradation in the Planning and Building Act, in line with the prohibition against coastal zone construction. If the proposed amendment is adopted, LAVDAS would contribute to ensuring compliance with the regulations. The maps do not provide details of peat depth or peat bog conditions, but may indicate areas that should be investigated further before decisions are made.



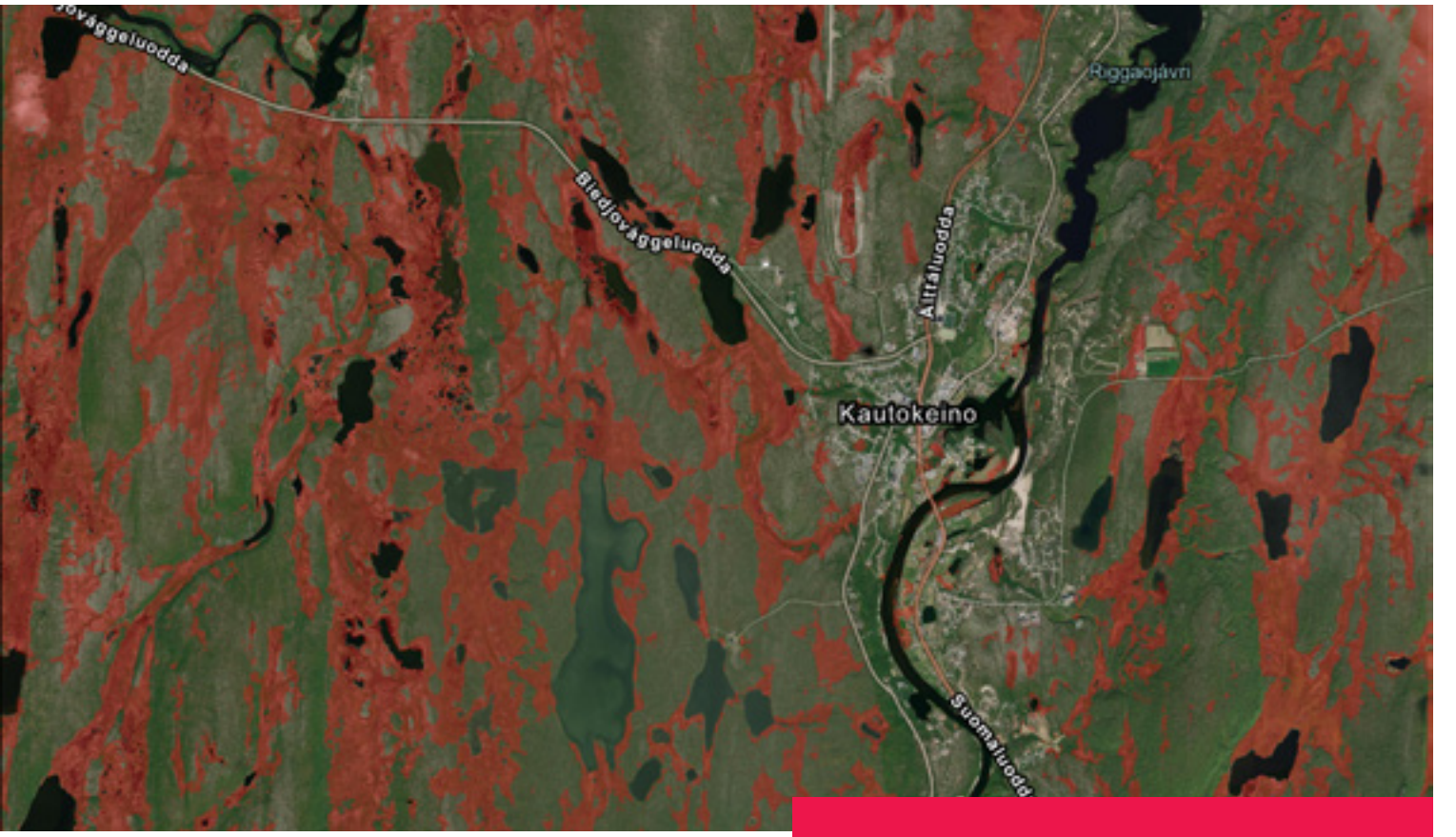
Astrid Marie Flattum Muggerud, project owner, and Carl William Lund, project manager, out in the field inspecting LAVDAS results. *Photo: Ole Magnus Grønli / Norwegian Mapping Authority*

THE CONTINUATION OF LAVDAS

Although the results so far are compelling, there are still challenges to overcome. Snow cover, cloud interference, shadows and logging areas can give rise to data interpretation errors. To counter this, the project is working towards including radar data from satellites and incorporating more and better training data, in order to provide more precise results. The project also aims to distinguish between different types of peatlands, including bogs fed by precipitation and fens fed by mineral soil or groundwater. This will provide an even more reliable scientific basis for natural resource management.

Even with these advances, important research remains to be done. LAVDAS only shows what is visible on the surface. Additional metrics and field surveys are still needed to better understand peatland condition, depth and structure.

Future projects could be platformed on LAVDAS and contribute to a more complete picture of Norwegian wetlands. ■



Example of LAVDAS results from the area around Kautokeino. Red colour indicates areas with >60% likelihood of being wetland. *Map: Carl William Lund / Norwegian Mapping Authority*

FURTHER READING:

The Norwegian Computing Center website has additional information on the LAVDAS project at *https://nr.no/en/projects/using-deep-neural-networks-to-map-wetlands-lavdas/*

The National Wetlands Geospatial Database is presented on page 37 of EuroSDR's annual report for 2024, available at *https://www.eurosdr.net/sites/default/files/uploaded_files/eurosdr_annual_report_2024_updated.pdf*

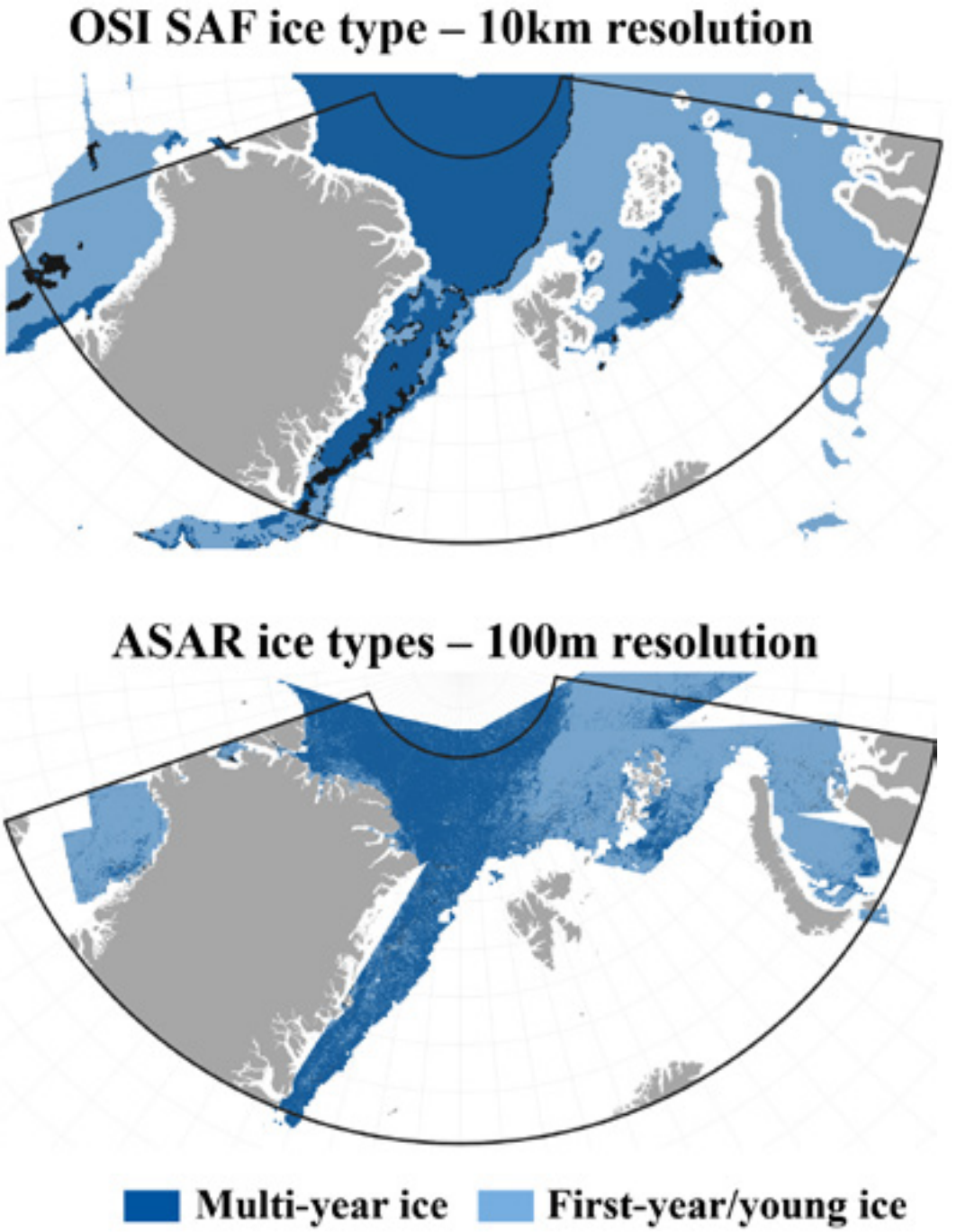
Maps (in Norwegian) are available digitally at *https://norgeskart.no and https://kilden.nibio.no*

WHAT IS A PROBABILITY MAP?

A probability map in LAVDAS shows how likely it is that an area belongs to a certain type of nature, in this case wetlands. To use the map in practice, a **threshold** must be set as a criterion for what may be classed as "peatland", "non-peatland" or "indeterminate". Such maps provide a more nuanced picture of uncertain landforms than conventional binary boundaries ("yes/no" maps).

ACKNOWLEDGMENTS

The LAVDAS project (NFR 349504), funded by the Research Council of Norway and the Norwegian Environment Agency, is a collaboration between the Norwegian Mapping Authority, the Norwegian Environment Agency, the Norwegian Institute of Bioeconomy, the Norwegian Institute for Nature Research and the Norwegian Computing Center.



Examples of sea ice type maps of the Atlantic Arctic for 15 January 2010, showing the improvement in spatial resolution from a typical existing global ice type product, based on NASA passive microwave satellite data (top), and SAR-based sea ice classification (bottom, using Envisat ASAR data).

Wenkai Guo and Jack Landy // UiT The Arctic University of Norway
Shiming Xu // Tsinghua University, China
Sebastian Gerland // Norwegian Polar Institute

Norway and China collaborate on remote sensing in a changing Arctic Ocean

RESEARCH NOTES

The Arctic climate is under rapid transformation, visible not least in the disappearance of sea ice. This is a global concern, demanding an international response. Here we describe one effort to meet this challenge: the INTERAAC project.

The INTERAAC (air-snow-ice-ocean INTERactions transforming Atlantic Arctic Climate) project is a collaboration jointly funded by the Research Council of Norway and the Ministry of Science and Technology of China. The project unites partners from the two countries: UiT The Arctic University of Norway and the Norwegian Polar Institute (NPI), both in Tromsø; Tsinghua University and the Chinese Academy of Meteorological Sciences (CAMS), both in Beijing; and the Polar Research Institute of China (PRIC) in Shanghai. Together, they hope to create unprecedented insights into the changing Arctic environment.

The project aims to characterise changes in sea ice within the Atlantic Sector of the Arctic, a powerful regulator of the regional climate system, over the past three decades. This is achieved by harnessing a wealth of Earth Observation data from satellites and benefiting from several completed Arctic scientific expeditions such as N-ICE[2015], MOSAiC,

INTERAAC activities: Norwegian scientists installing a snow ice mass balance apparatus during the CIRFA2022 research cruise. *Photo: Christian Zoelly / Norwegian Polar Institute*

Participation in the Alfred Wegener Institute IceBird Summer airborne sea ice remote sensing campaign in August 2024, when the AWI Polar 5 overflew RV *Kronprins Haakon* in the Central Arctic Ocean. *Photo: Jack Landy / UiT The Arctic University of Norway*

Nansen Legacy–already familiar to readers of Fram Forum–and the FACE (Following Arctic sea iCE) campaigns, run on board the Chinese icebreaker Xuelong 2. The project's ultimate goal of understanding the interactions between air, snow, ice and ocean is crucial for projecting future climate pathways in the Arctic, which has significant implications for inhabitants of the High North and beyond.

EXAMPLES OF RESEARCH ACTIVITIES

The INTERAAC project has produced enhanced observational datasets for key sea ice parameters in the Atlantic Arctic, including sea ice coverage, ice types, and ice and snow thickness. UiT brings in the Earth Observation Group's expertise with sea ice remote sensing to retrieve sea ice type and thickness measurements using satellite Synthetic Aperture Radar (SAR) and altimetry; NPI analyses vast datasets from *in situ* field campaigns to constrain sea ice processes observed at scale through remote sensing; Tsinghua University are experts in synergising satellite observations from different missions and integrating the data with sea ice and climate modelling; and CAMS and PRIC provide unique field data collected during Chinese polar research expeditions.

Working together, the team has made significant progress in several key areas. Novel methods have been developed to reconcile legacy and modern C-band radar frequency SAR sensors, enabling estimates of the sea ice type (for example thin ice, level ice, deformed ice, and old ice) to be derived across a 35-year record spanning 1991 to present. Although satellite image coverage over the Atlantic Sector of the Arctic was less rich in

A Chinese scientist (left) deploying an ice buoy during one of the yearly Arctic expeditions carried out by Xuelong 2, one of China's icebreakers (right).
Photos: Lin Long / Polar Research Institute of China

the 1990s than it is today, in some key locations this new record has revealed trends in sea ice types–with the replacement of old ice by thinner, younger sea ice–at a level of detail unprecedented with conventional datasets. The SAR record is 100 times more detailed than the information available from existing climate data records. This allowed the team to establish a statistical model for upscaling satellite altimetry measurements of the sea ice freeboard and thickness.

RESEARCH VISITS AND COLLABORATIONS

The collaboration between the Norwegian and Chinese partner institutions has been actively strengthened through a series of mutual visits and in-person exchanges. In 2023, project partners from Beijing visited Tromsø where an in-person workshop was held in Árdna, UiT's Sami cultural building. In 2025, project members from UiT and NPI visited Beijing for the second in-person workshop. These workshops allowed the project team to jointly refine scientific questions, align data and methods, and plan coordinated research and outreach activities. In addition, early-career researcher Wenkai Guo from UiT completed two research stays at Tsinghua University, while Associate Prof. Shiming Xu from Tsinghua University undertook a corresponding stay at UiT. By strengthening collaboration both between and within Norway and China, and also with other international research teams and projects (e.g., EU Arctic PASSION), INTERAAC builds towards future initiatives like the Arctic Ocean 2050 project and upcoming Earth Observation satellite missions. It has laid a strong foundation for sustaining and expanding Norway-China research collaborations on polar and climate topics in the coming years. ■

Terri Souster // UiT The Arctic University of Norway
Bernabé Moreno // Institute of Oceanology, Polish Academy of Sciences
Katherine M Dunlop // Institute of Marine Research
David KA Barnes // British Antarctic Survey, Cambridge, United Kingdom

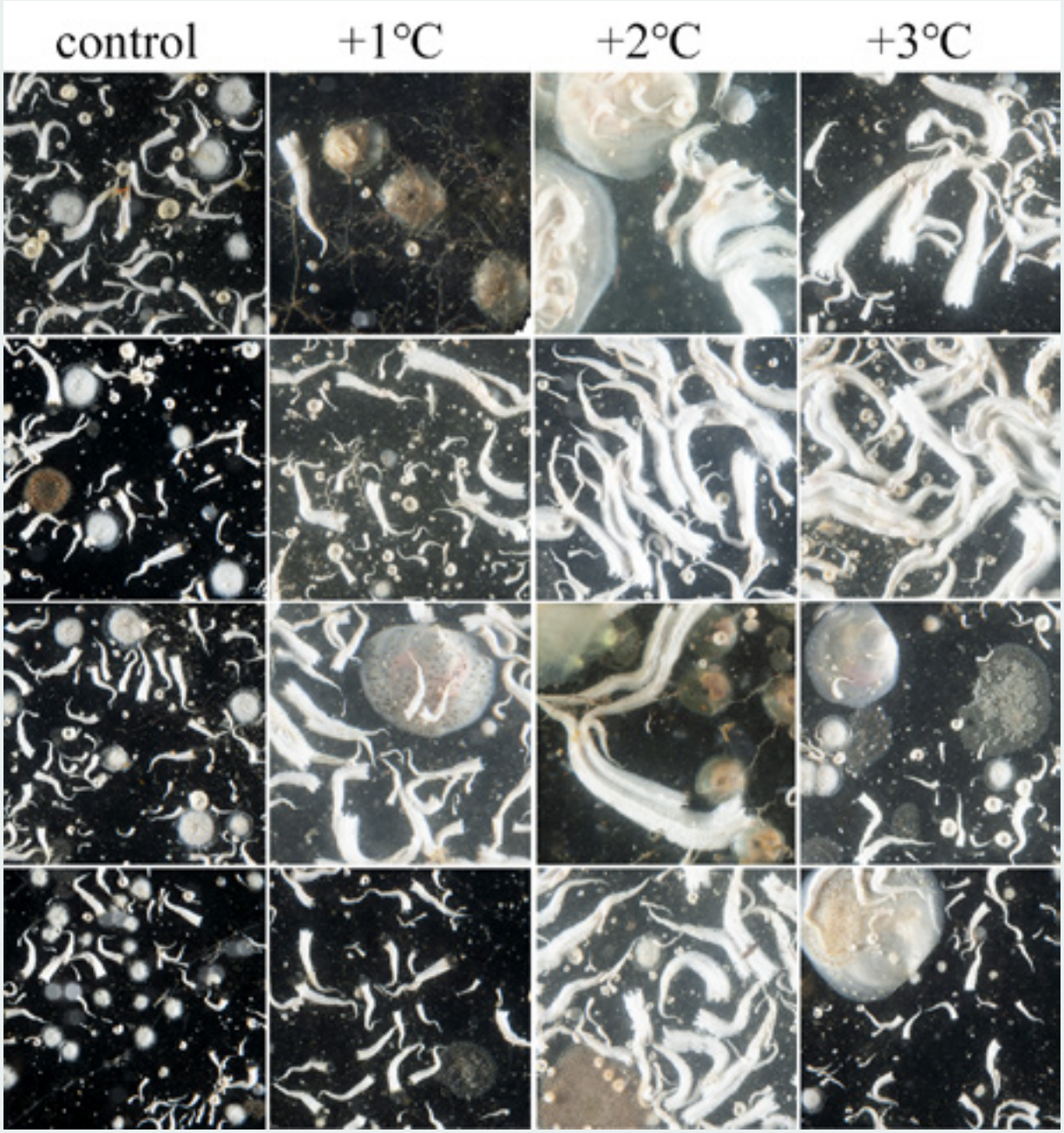
Turning up the heat! Settlement of benthic organisms in warming waters

RESEARCH NOTES

Arctic coastal waters are undergoing some of the world's most severe warming. Laboratory studies that simulate raised sea temperatures suggest that some species living on shallow polar seabeds are supremely sensitive to warming. Now we want to test their sensitivity in real-world conditions.

It is possible to investigate how warming impacts assemblages of species in their natural habitat, without changing other variables. Man-made panels that emulate a hard surface for benthic organisms to settle on have been used for nearly a century to investigate colonisation, recruitment, and assemblage succession in coastal and subtidal habitats. If connected to nearby power supplies, these panels can be heated to provide a small area of colonisable surface at a set temperature above ambient. This method has been used successfully in western Australia, West Antarctica and the UK to examine how macrobenthic species respond to sustained temperatures +1 and +2°C above ambient. Unheated panels serve as controls, to show the species' responses to the ambient temperature.

Location of the Heated Settlement Panel (HSPl) experiment in Andersdal (Tromsø Municipality, northern Norway). Bottom left: Metal frame at 10 m depth in the circalittoral zone, supporting both heated treatments and controls, replicated on each side. Bottom right: The electric control panel was housed at a nearby farm, which also provided electrical power. *Figure modified from Moreno et al (2025).*



A mosaic of heated settlement panels after 12 months' submersion in the Arctic (69.5°N), zoomed in to different regions of interest. Treatments as columns, replicates as rows.
Photos: Bernabé Moreno / Institute of Oceanology, Polish Academy of Sciences

Retrieving the HSPl array from 10 m depth in March 2025. The panels were photographed in the intertidal zone, then returned to 10 m. *Photo: Lea Burellier / UiT The Arctic University of Norway*

Although much is already known about early colonisation, competition, and growth on natural substrates and unheated subtidal settlement panels in the Arctic, heated settlement panels (HSPls) have never previously been used there. Thus, our study offered the first opportunity to test warming effects *in situ* in the Arctic. Manipulative experimental fieldwork at high latitudes is essential for understanding the mechanisms underlying ecological change processes. Improved knowledge will aid in predicting responses both to differing levels of warming–a key stressor–and ecological tipping points in cold-water ecosystems under projected IPCC climate scenarios.

Dr Terri Souster (looking absurdly happy) on site in the intertidal zone to photograph heated settlement panels. *Photo: Emily Venables / UiT The Arctic University of Norway*

POLAR ORGANISMS' RESPONSES TO HEAT

Cloches have been widely used in polar land habitats to investigate how mosses, lichens and hardy flowering plants, as well as insects and other small animals, might respond to varying degrees of warming. This task is more challenging in the sea below the shoreline, not least because it requires scuba diving. However, a study involving an identical HSPl near the UK Rothera research station along the Antarctic Peninsula proved that this apparatus functions well in polar conditions. That study, led by Dr Gail Ashton, showed many key points about how shallow-water species respond to southern polar warming.

Across a nine-month deployment, temperatures 1°C above ambient increased the growth of some pioneer species. In contrast, 2°C warming increased the variability in growth of many species. When spatial interference competition between those recruits was examined at those same temperatures, +1°C increased the probability, density, and complexity of contests for space between competitors. At +2°C warming it was, again, mainly the variability of competition that changed, rather than the intensity, just as for growth. However, ambient sea temperatures along Antarctic coasts are typically cooler and much more constant than in the Arctic and the evolutionary history of biodiversity is very different. We hope that running heated panels in an Arctic fjord will give powerful insight into how colonisation of newly available space will occur in a rapidly warming world.

MANAGING MARINE ECOSYSTEMS

Establishing the heated panels generated a new set of challenges, not least in how to photograph at high resolution despite a strong halocline. Preliminary results show that small increases in water temperatures impact which benthic organisms settle and grow; this could potentially alter the species composition of benthic assemblages that establish and thrive in Arctic coastal waters.

Colonisation was dominated by encrusting tube-forming polychaete worms, but many other taxa such as bivalve molluscs, bryozoans and others were present. The variability in colonists—both within and across treatments—was considerable. Identifying them will require detailed, painstaking collaborative effort. Once the species are identified, we can measure densities, sizes and interactions and begin to tease out the key effects.

Many important questions remain about the impact of warming waters on benthic communities. Will warming favour the settlement and growth of invasive species such as colonial tunicates and would that promote biofouling on fish farms and pipelines? The heated settlement panels can help us find answers relevant to management of High North coastal ecosystems.

Sustainable management and climate adaptation in coastal areas requires an improved understanding of the cumulative risk that multiple anthropogenic stressors pose to ecosystem health and services. For marine spatial planning, and

to follow the EU water framework directive, it is crucial to assess the impact of human activities on benthic communities within the context of climate change. Manipulative field studies allow to us investigate and quantify climate change effects *in situ*, providing the knowledge base for upscaling prediction to larger areas of relevance to management. Collection of data that increase understanding of how climate change may affect the ecology of Arctic ecosystems is also of great public interest, and the HSPl project enjoyed strong support from local residents.

Recent cross-institutional efforts, formalised through the Fram Centre-funded HSPl project helped ensure the success of the first Arctic trial of heated settlement panels. Future work is expected to couple heated panel experiments with *in situ* sensors, machine-learning image annotation, and genetic sampling of early colonisers to capture both ecological and physiological processes. ■

ACKNOWLEDGMENTS

We are grateful to Mark Preston (British Antarctic Survey) for building, testing and manufacturing heated panels; to the community at Indre Andersdal for supporting the project and providing electricity; to UiT for access to small boats for field work; and to the entire team for their contributions to the project's success.

This QR code will take you to a video showing the logistics required for the HSPl experiment in the Arctic.

FURTHER READING:

Ashton GV, Morley SA, Barnes DKA, Clark MS, Peck LS (2017) Warming by 1°C Drives Species and Assemblage Level Responses in Antarctica's Marine Shallows. Current Biology 27: 2698–2705, *https://doi.org/10.1016/j.cub.2017.07.048*

Barnes DKA, Ashton GV, Morley SA, Peck LS (2021) 1 °C Warming Increases Spatial Competition Frequency and Complexity in Antarctic Marine Macrofauna. Communications Biology 4: 208, *https://doi.org/10.1038/s42003-021-01742-w*

Moreno B, Peck LS, Clark MS, Dunlop KM, Barnes DKA, Bluhm B, Molis M, Ziegler A, Longsden J, Hatt A, Jordà Molina È, Souster T (2025) Heated settlement plates (HSPl) in global experimentation: Experiences, research questions, future applications and collaborations. Research Ideas and Outcomes 11: e174994. *https://doi.org/10.3897/rio.11.e174994*

Lionel Camus, Kanchana Bandara and Pierre Priou // Akvaplan-niva

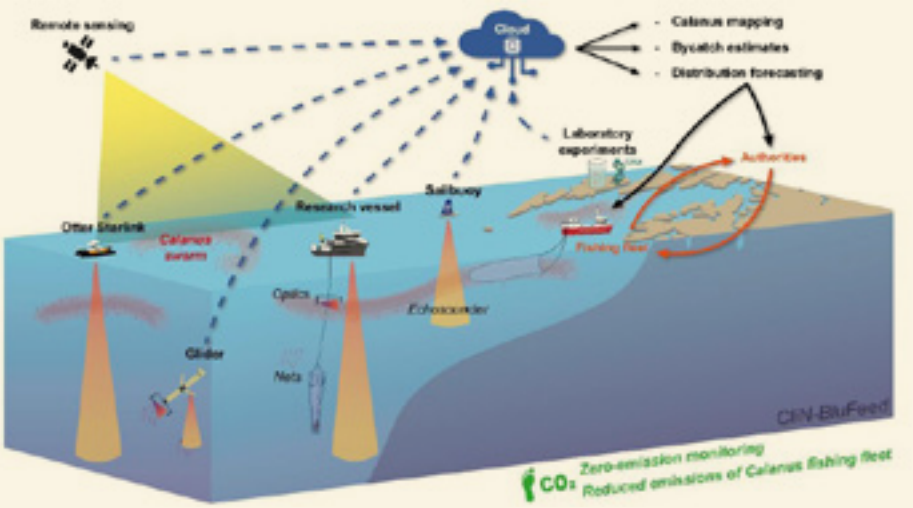
CliN-BluFeed—a quest for sustainable fish feed for the aquaculture industry

RESEARCH NOTES

Global demand for food is increasing. To meet this need, aquaculture has also expanded and is forecast to produce 60% of all fish for human consumption by 2030. This means the aquaculture industry must find sustainable sources of fish feed. One possibility is the marine copepod *Calanus finmarchicus.*

TODAY MUCH OF THE FEED USED in fish farming is sourced from captured wild fish, making the sustainability of aquaculture questionable. Therefore, the aquaculture industry is on the lookout for sustainable feed sources. A marine copepod, *Calanus finmarchicus*, a crustacean about 1-2 mm long and abundant in the Norwegian Sea, offers an easily accessible lower trophic level resource. The copepod is rich in lipid, making *C. finmarchicus* a high-energy food source for many planktivorous fish and also an attractive feed ingredient in fish farming. Currently, the Norwegian company Calanus AS is processing and distributing *C. finmarchicus* harvested in the coastal waters of northeast Norway. The present-day harvest is estimated at about 0.5% of the annual quota set by the Norwegian Institute of Marine Research and accounts only for 0.00004% of the estimated *C. finmarchicus* stock in the Norwegian Sea.

The Sailbuoy rigged with an echo sounder, and two Seagliders rigged with an optical imagery plankton sensor (UVP6) and an echo sounder.
Photo: Pierre Priou / Akvaplan-niva



Research activities in the CliN-BluFeed project involve *in situ* shipboard plankton sampling, autonomous vehicles with sensors, space borne measurement of ocean colour and ocean height, and *ex situ* experiments of copepod behaviour. Data are fed into a 3D forecasting model to assess *Calanus* stock and distribution. Outputs can be delivered in real-time to stakeholders to develop a climate-neutral sustainable fish feed for the aquaculture industry.

THE CLIN-BLUFEED PROJECT

Full title:
A low-CO_2 smart autonomous multiplatform system to monitor and forecast *Calanus finmarchicus* stock—a new sustainable climate-neutral blue fish feed

Partners:
Akvaplan-niva (Norway)

Institute of Oceanology, Polish Academy of Sciences (Poland)

Atlantic International Research Centre (Portugal)

Cyprus Subsea Consulting and Services (Cyprus)

Alfred Wegener Institute (Germany)

With the expansion of the aquaculture industry, the potential for the *Calanus* fishery to grow is large. This calls for managing the stock of this highly valuable marine resource to ensure a sustainable fishery. To that end, the European Union's Sustainable Blue Economy Partnership funded the project CliN-BluFeed. The main objective is to develop methodologies that advance the Norwegian Sea *Calanus* fishery as a sustainable climate-neutral blue resource for the aquaculture industry. This will be done through harnessing the potential of cutting-edge, low-carbon-emission autonomous marine monitoring technologies coupled with remote sensing, artificial intelligence, simulation modelling, and experimental investigations (see diagram above).

Calanus collected in the field. *Photo: Pierre Priou / Akvaplan-niva*

Two successful field surveys were conducted in 2024 in collaboration with the project "Migratory Crossroads" financed by the Research Council of Norway. In these surveys, autonomous uncrewed vehicles (AUVs) equipped with advanced sensors were deployed from a research vessel. The work continued in 2025 when the team demonstrated that the AUV could be deployed and recovered from the shore without the support of a research vessel. The AUVs were one Sailbuoy rigged with an echo sounder and two Seagliders rigged with the optical imagery sensor UVP6 and a echo sounder. The echo sounder detects and quantifies plankton biomass, and the UVP6 is used to visualise, identify and quantify plankton species. Parallel with the AUVs collecting data during a month at sea, the team collected satellite images from the European Space Agency's Copernicus to collect information on the ocean colour and from a NASA satellite with a LIDAR sensor that can penetrate the upper 20-30 m of the ocean. In addition to this, laboratory experiments were performed to study the copepod behaviour. All collected data were then used to develop and support a population model that can predict copepod presence and density across time and ocean space.

The knowledge and cutting-edge methodologies and technological solutions provided by the CliN-BluFeed project will secure evidence which will support and improve the understanding and management of our marine ecosystem, with value creation effects for both industry and society. ■

The cargo vessel at the ice edge, unloading supplies for Troll Station in 2021. *Photo: Stein Tronstad / Norwegian Polar Institute*

Deep ocean mooring equipment being made ready for deployment in Kong Haakon VII Hav. *Photo: Tore Hattermann / Norwegian Polar Institute*

Tore Hattermann, Sebastien Moreau, Kristen Fossan, Heidi Ahonen, Sebastien Descamps, Agneta Fransson, Sebastian Gerland and Katrine Husum // Norwegian Polar Institute
Melissa Chierici // Institute of Marine Research
Terri Souster and Monica Winsborrow* // iC3: Centre for ice, Cryosphere, Carbon and Climate

TrollTransect: No free ride, but much to be gained

RESEARCH NOTES

When the red supply vessel departs Cape Town around Christmas, bound for Troll Station in Dronning Maud Land, Antarctica, it holds more than fuel and provisions. Nestled among the containers are purpose-built laboratories, instruments and sensors: part of the TrollTransect observation platform.

EVERY SOUTHERN HEMISPHERE SUMMER since the all-year Antarctic research station Troll was opened in 2005, Norway has carried out supply operations. However, in 2020, when the world was in the midst of the COVID pandemic, this logistical necessity was transformed into a scientific opportunity: a small multidisciplinary team of scientists joined the supply vessel on its voyage across the globe from the High North to the Antarctic coast. Since then, the TrollTransect cruises have made systematic observations and collected data in Kong Haakon VII Hav, previously one of the least studied regions of the Southern Ocean. Integrating research into annual supply operations has created a cost-effective and sustainable framework for collecting climate-relevant data from the Antarctic. Spearheaded by the Norwegian Polar Institute and the Centre for ice, Cryosphere, Carbon and Climate (iC3) the programme supports Fram Centre efforts to understand interactions between the cryosphere, ocean, and atmosphere in a changing climate.

*Both affiliated with UiT The Arctic University of Norway

Deploying a microstructure profiler to study turbulence under the sea ice.
Photo: Sebastien Moreau / Norwegian Polar Institute

TURNING CARGO RUNS INTO SCIENCE

The voyage between Cape Town and Antarctica's icy coast follows a tight choreography, combining oceanographic measurements, biological sampling, sea ice work, and ecological surveys with logistical needs. The scientific objectives address pressing questions of the ocean's influence on the Antarctic ice sheet stability and sea level, the fate of sea ice in the Southern Ocean, and the functioning of a marine ecosystem that supports abundant wildlife and contributes significantly to the global carbon cycle:

- **Oceanographic measurements** comprise repeated Conductivity-Temperature-Depth (CTD) transects, turbulence microstructure profiling, and maintenance of the Troll Observing Network Multidisciplinary Ocean Moored Observatory. These so-called TONe-MOMO moorings collect physical, biogeochemical, and biological data across the continental slope off Dronning Maud Land, contributing to long-term monitoring of Circumpolar Deep Water and its influence on ice shelf melting and sea-level rise. The upper 200 m of the mooring structure is mounted with an innovative weak-link technology, which allows us to place sensors close to the iceberg-infested surface waters, providing unique data and process understanding of the Antarctic seasonal sea ice zone.

- **Sediment traps** deployed and recovered during mooring maintenance capture the vertical flux of organic matter, its quantity and composition (i.e., ice algae, phytoplankton, zooplankton exoskeletons and faecal pellets as well as marine snow), and offer insights into biological

A curious Adelie penguin watches what's going on. *Photo: Sebastien Moreau / Norwegian Polar Institute*

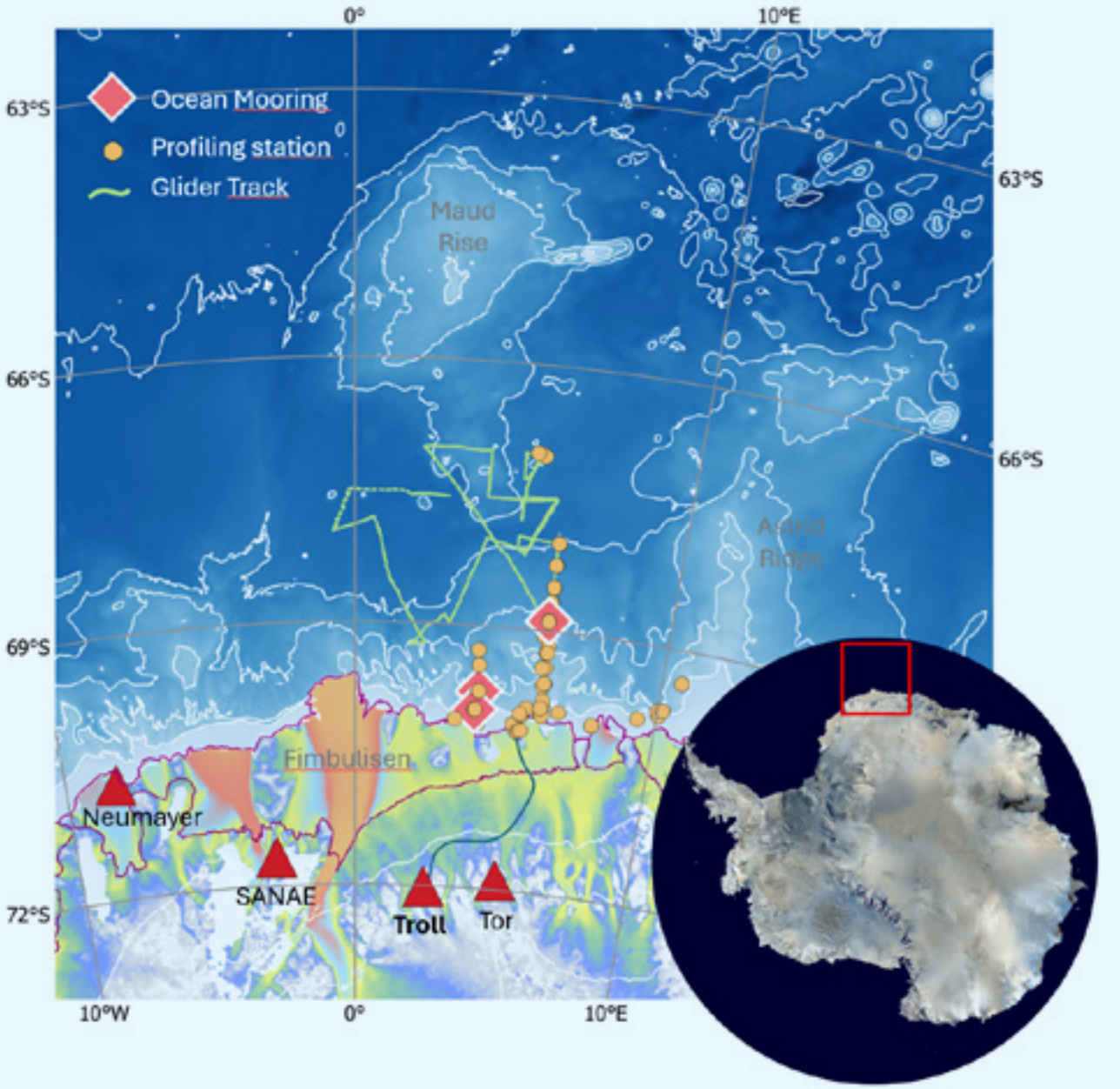
The TrollTransect 2023 science crew, left to right: Johanne J Hus, Megan Lenss, Jan A Jakobsen, Tore Hattermann, Sebastien Moreau and Kristen Fossan. *Photo: A Andreassen / Silversea*

carbon export and the ocean's capacity to sequester carbon, a particularly important process in the Southern Ocean.

- **Sea ice surveys** include ship-based monitoring following a standardised setup, ice stations on both drifting sea ice and landfast sea ice (contributing to the Antarctic Fast Ice Network AFIN) with snow and ice thickness measurements and sea ice core collection.

- ***In situ* sampling of ice, ocean, and sediments** reveals processes that are shaping the regional physical and ecological environment and carbon cycle. Ice cores and seawater are analysed for physical, biological and biogeochemical properties. A suite of multidisciplinary indicators is collected, such as physical sea ice properties and crystal texture, chlorophyll *a* (the main algal pigment) and algal species, particulate organic carbon and nitrogen, biogenic silica, nutrient concentrations, dissolved inorganic carbon and total alkalinity, as well as noble gas and oxygen stable isotopic ratios, which together provide thorough insights on the system dynamics and its change. Strategic acquisition of sediment cores provides further insights into ice sheet behaviour, carbon and nutrient cycling both past and present.

- **Systematic marine wildlife observations**, conducted from the ship's bridge, and passive and active acoustic sensors on the TONe-MOMO moorings establish a baseline by documenting the seabird and marine mammal but also fish and zooplankton communities that use these waters along a large latitudinal gradient, providing critical information in a data-poor



The TrollTransect study region, showing repeat ocean profiling and mooring positions. White contours are 1000 metre isobaths; purple contours delineate the floating ice shelf. *Figure: Tore Hattermann / Norwegian Polar Institute. Mapping tools: Quantarctica (see Matsuoka et al, Environ Model Softw 140:105015, 2021, https://doi.org/10.1016/j.envsoft.2021.105015). Inset: NASA*

region. They reveal how important sea-ice habitats and the marginal ice zone are as foraging areas for birds and mammals, highlighting the ecological role of these dynamic environments. Annually repeated surveys reveal changes in wildlife density, community composition, and overall biodiversity over time, offering insight into how these marine ecosystems respond to ongoing environmental changes.

- **Opportunistic deployments of gilders** and ice-capable BGC-Argo floats enlarge the footprint along the ship's route in the sea ice zone, north of Maud Rise, or even in the waters of the Antarctic Circumpolar Current.

Together, these data provide a comprehensive picture of the interplay between the ice sheet, ocean, sea ice, ecosystems, and the movement of carbon at the Antarctic margin. In addition, the unique platform stimulates participation of early career scientists in research cruises, giving rise to multiple publications, attracts international attention in the Antarctic research community, and enables successful applications for external funding.

LEVERAGING LOGISTICS: PROS AND CONS

Using a resupply vessel as a research platform has both clear advantages and practical limitations. TrollTransect's strength lies in its regularity and sustainability–its cruises are guaranteed by operational necessity rather than the availability of costly research charters. This ensures a long-term commitment to build climate-relevant time series that rarely exist in the Southern Ocean but are essential for detection of change and process understanding.

The use of containerised laboratories that can be set up on the cargo hatches of the container vessel has proven highly effective. A purpose-built winch container and A-frame provide safe and flexible options for water profiling and sampling and deployment of deep-ocean moorings. Self-contained heated and insulated containers provide a wet-lab for water sampling, laboratory benches, an instrument control room, and an electrical workshop, creating functional workspaces even on a ship not designed for research activities.

However, the phrase "no free ride" aptly captures the challenges. Resupplying Troll Station remains the primary mission of the voyage, and the science operations are fit in to utilise logistical opportunities. Researchers are typically allocated one week for data collection during the 40-day voyage, and schedules must adapt to weather, ice conditions, and operational demands. As the ship is not designed for many passengers, work is done by a small team–usually five to seven scientists and engineers–who play multiple roles to make efficient use of limited time. Although fit-for-purpose, the technical solutions in our "container village" are far from foolproof and require awareness and the capability to improvise from their users. On the upside, the science teams that have worked on three different ships over the past few years have always perceived the captain and crew of the supply vessel as extremely supportive and helpful.

The work is demanding, the space is limited, and the schedule is tight–but the rewards are significant, contributing further knowledge on climate and ecosystem dynamics that are of global interest and support sustainable management of remote but important marine areas. Each voyage adds a new chapter to our understanding of the Southern Ocean and reinforces a simple truth: there may be no free ride in Antarctic research, but there is much knowledge to be gained. ■

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Halfdan Pascal Kierulf and Carl William Lund // Norwegian Mapping Authority
Thomas Vikhamar Schuler // University of Oslo

Glacier melt lowers pressure on land—and puts pressure on societal systems

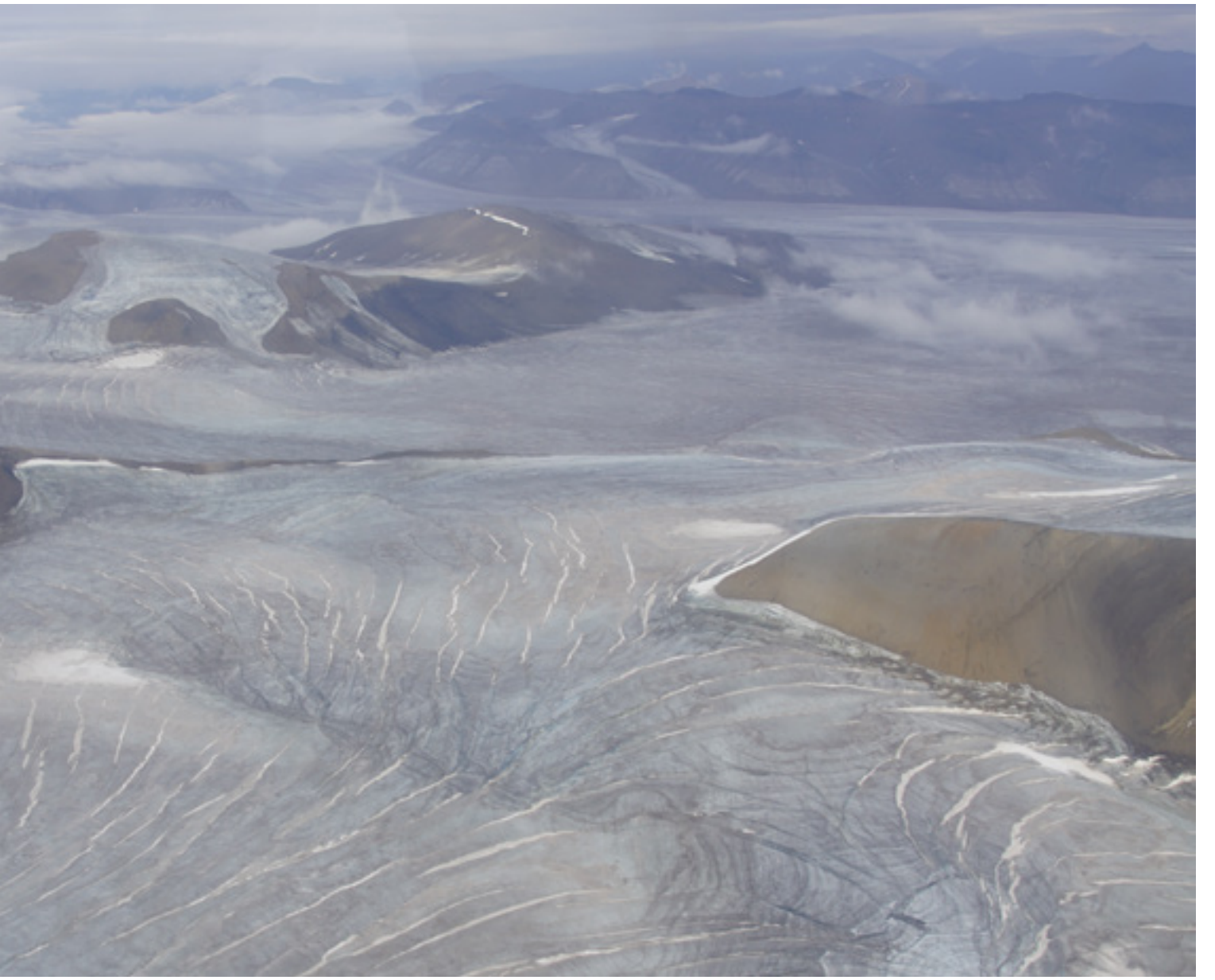
RESEARCH NOTES

The summer of 2024, the hottest on record, pushed the limits of what we thought possible in the Arctic. In Svalbard, glaciers melted on an unprecedented scale: across the entire archipelago, around 1% of the total ice mass disappeared in a single season. What does that mean for Svalbard—and for us?

When glacier ice disappears, the pressure on the earth's crust is relieved and the ground rises. This is happening faster than in the past, and measurements from the Norwegian Mapping Authority's Geodetic Earth Observatory show that the land around Ny-Ålesund rose by almost two centimetres between July and October 2024.

Movements of a few millimetres may be imperceptible to the casual observer, but have major implications for maps, property boundaries and a global navigation system that relies on millimetre precision. The land uplift caused by the extreme glacier melt in Svalbard during the summer of 2024 was so substantial that it affected the global frame of reference, i.e. the coordinate system used to describe exact positions on Earth, and thus also global Earth observation.

The land uplift seen in 2024 was basically a natural reaction to an abnormal situation. But when a changing landscape conflicts with society's need for stable boundaries, accurate maps and reliable navigation systems, national agencies must take action. Svalbard reminds us that climate change not only melts ice, but also alters the parameters on which we base our systems.

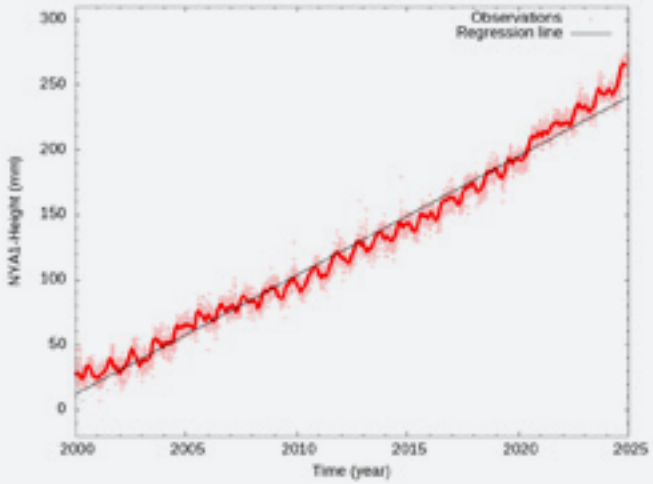


In August 2024, large glacier areas were free from the usual snow cover in zones higher than 600 metres above sea level. The photo was taken over Sveabreen glacier looking towards Sefströmbreen glacier, between Longyearbyen and Ny-Ålesund, Svalbard. *Photo: Thomas Vikhamar Schuler / University of Oslo*

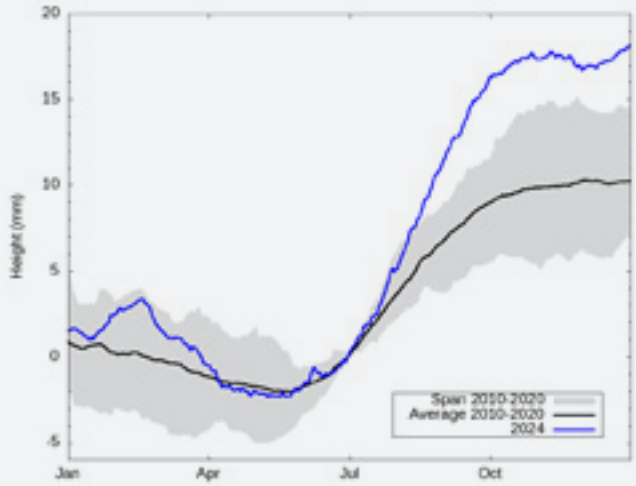
HINTED AT END-OF-CENTURY CONDITIONS

Svalbard's summer heatwave in 2024 resulted in significant glacier melting. The ice mass loss was quantified by a combination of ground observations, modelling and remote sensing. The results indicated an ice mass loss of around 61.7 gigatonnes, of which 42.1 gigatonnes were from the surface balance (the balance between snowfall and melting) and the remaining 19.6 gigatonnes were lost as calving icebergs. In total, this corresponds to approximately 1% of Svalbard's total glacier mass, and is comparable to the total loss of ice mass from the Greenland ice sheet in 2024, even though the latter is fifty times larger. Glacier mass loss contributes to global sea level rise and has potential impacts on fjord circulation and marine ecology, as well as on native wildlife and local communities.

The meltdown exceeded all previous records by a wide margin. All parts of Svalbard experienced mass losses at a level that is expected to occur in the current climate (1991-2020) only once in a few hundred or perhaps thousand years. The unprecedented land uplift measured in Ny-Ålesund in the



Land uplift in Ny-Ålesund since 2000. Daily values are pale red and the 60-day average is bright red. In total, Ny-Ålesund has risen more than 25 cm since 2000. *Graph: Halfdan Pascal Kierulf / Norwegian Mapping Authority*



Seasonal variations in land uplift in Ny-Ålesund, Svalbard. Blue represents the year 2024; black is the average of the years 2010-2020. *Graph: Halfdan Pascal Kierulf / Norwegian Mapping Authority*

summer of 2024 has similar likelihood statistics and was used for independent confirmation of the huge mass loss.

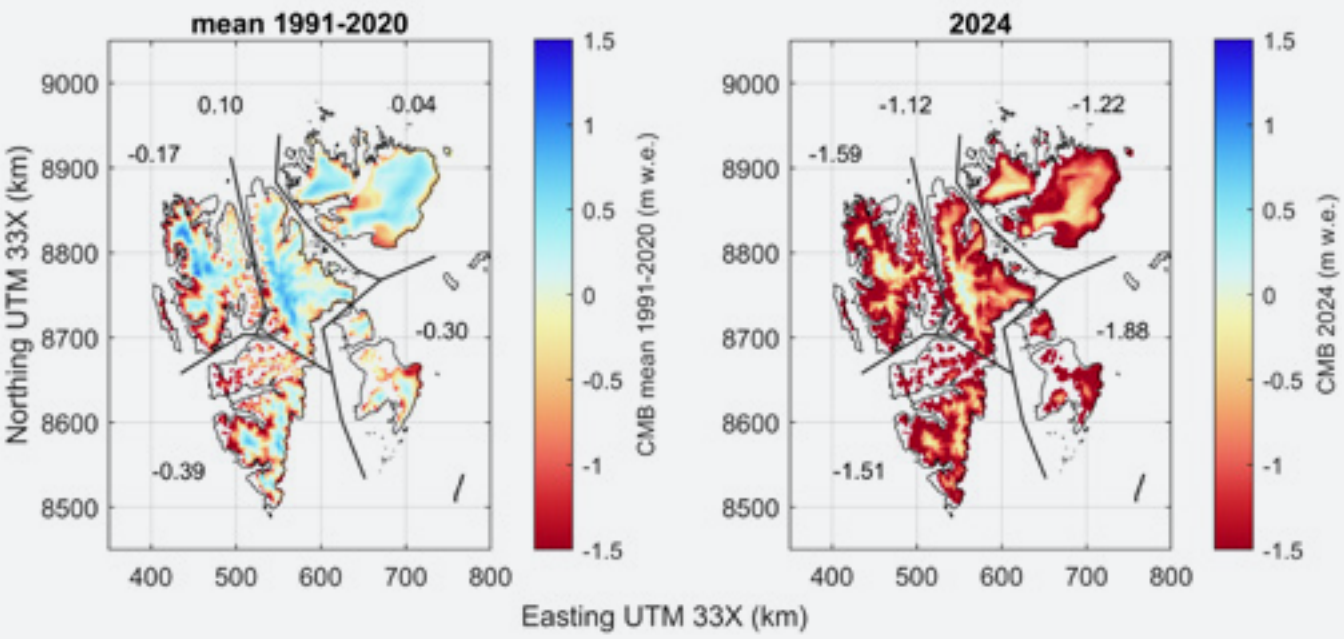
Much of the melt occurred during a six-week period when a steady weather pattern resulted in temperatures well above normal. Although such conditions are extremely rare under prevailing climatic conditions, climate models suggest that temperatures this high may be commonplace by the end of the 21st century. The summer of 2024 in Svalbard is thus a harbinger of widespread melting of Arctic glaciers in coming decades.

GEODETICS IN A DYNAMIC SVALBARD

In Scandinavia, land uplift or rebound is a well-known phenomenon. As ice retreated at the end of the last ice age, the land reacted by rising.

This slow process, which can still be observed 10,000 years after the ice disappeared, is termed isostatic rebound. The colossal ice mass changes seen in Svalbard today are having a more rapid effect. When the glaciers melt, the pressure on the bedrock is released, causing immediate uplift. In the summer of 2024, the ground uplift was two centimetres in three months, twice the uplift in a normal summer. Through the winter, we see the opposite: the ground is forced down a few millimetres as the snow settles.

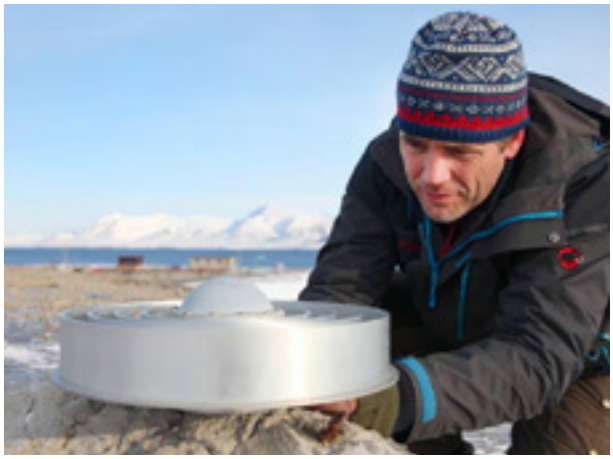
These changes have a direct consequence. Land uplift affects the very basis for measuring the earth, termed the geodetic basis. The Geodetic Earth Observatory in Ny-Ålesund, northwest Svalbard, is one of the most important in the world for monitoring the earth's rotation and movements in the earth's crust. Here we receive



The estimated surface balance (climate mass balance) of Svalbard glaciers (in metres water equivalent) for the normal period 1991-2020 (left) and in 2024 (right). Blue indicates areas where the glacier is building up mass and red indicates areas of mass loss. In 2024, mass loss occurred across almost the entire area. *Graph: Thomas Vikhamar Schuler / University of Oslo*

signals from quasars billions of light years away, transmit laser pulses to satellites, and use GPS and similar techniques to continuously record movements in the earth's surface. When the ground suddenly rises faster than normal, we must correct for the changes, otherwise the deviations can propagate throughout the entire earth observation system, making positioning and navigation less accurate. To increase our knowledge of the changes taking place, the Norwegian Mapping Authority is working to expand the global navigation satellite system network in Svalbard.

GPS is used in many essential systems such as aviation, shipping, power supply, emergency response, mobile communications and environmental monitoring. Stability and precision are not merely nice to have, but also essential societal infrastructure. This makes Svalbard, with its rapid



Measuring land uplift using GPS.
Photo: Bjørn-Owe Holmberg

Illustration of the experiment to calculate how many football pitches Svalbard has grown by. Here only a few of the estimated 148 pitches are shown. *Image generated using OpenAI.*

and measurable ice mass loss, one of the best places in the world to gain understanding of how the earth's crust reacts to climate change, and to generate knowledge essential for the global precision we all depend on.

MINOR UPLIFTS, MAJOR CONSEQUENCES

Using detailed terrain models for Svalbard, we did an experiment to visualise the measured land uplift. By calculating the average slope along the entire coast of Svalbard, it is possible to predict how much potential new land area rose from the sea around Svalbard in summer 2024. Assuming that the land uplift was uniform along the entire coast, the archipelago would have gained new land area equivalent to almost 150 football pitches. This is not an actual future scenario, but serves to illustrate how climate change can shift coastlines.

Changes to a coastline can have long-term consequences for maps, but legal and administrative issues also arise out of a mobile landscape. The Nordic region has useful parallels such as in Iceland, where volcanic eruptions can create new land, and one issue might then be who owns that land. In Denmark, severe erosion has resulted in private properties losing land, while the land register map still shows the property line far out to sea.

This demonstrates that even small uplifts can be significant. Foreshores change, shallows dry out, and river deltas flow into new distributaries. When permafrost meets sea level in new configurations, beaches and slopes take on a different shape. The sum of all such small adjustments will shape the Svalbard of tomorrow. ■

The Geodetic Earth Observatory is located at the far end of Brandallaguna in Ny-Ålesund, Svalbard. The Observatory now has its final skyline, with the new dome on the satellite laser ranging building between the two antennae. *Photo: Bjørn-Owe Holmberg*

NORWEGIAN GEODETIC EARTH OBSERVATORY, NY-ÅLESUND, SVALBARD

The Geodetic Earth Observatory in Ny-Ålesund is the northernmost facility of its kind and is part of a worldwide geodetic observation and research network. From the new observatory, the Norwegian Mapping Authority measures the earth's movement and position using several geodetic measurement techniques at the same location.

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ACKNOWLEDGMENTS

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Moss sampling close to Hammerfest in the middle of the night. *Photo: Jenny Jensen / Akvaplan-niva*

Tore Flatlandsmo Berglen, Christine Forsetlund Solbakken and Hilde Uggerud // NILU
Jenny Jensen and Guttorm Normann Christensen // Akvaplan-niva
Tone Roksvåg Aandahl // Norwegian Institute of Bioeconomy Research (Svanhovd)

Moss as an environmental indicator

RESEARCH NOTES

Did you know that stairstep moss can be used as a sampler for air pollution? Researchers at NILU have collected this kind of moss on several occasions and examined it for metals and other pollutants.

Stairstep moss (*Hylocomium splendens*) is commonly used as an indicator plant for the deposition of air pollution. It has no root system and receives all its nutrition from precipitation and deposition through air.

As a pollution sampler, stairstep moss needs neither electricity nor supervision. It forms a new "stairstep" each year, making it easily identifiable in the field. This growth pattern also makes it easy to find out which years each plant represents.

View southwards from Korpfjell 9. This station is located about 15 km north of Zapolyarny and only a few hundred metres from the Norwegian–Russian border. The islets and headlands in the picture are Russian territory. This area was the first part of Norway to be liberated during World War II, in October 1944. The bridge that the Russian Red Army used to cross Jakobselva River is a few hundred metres to the left outside the edge of the picture. *Photo: Tore Flatlandsmo Berglen / NILU*

THE MOSS METHOD

This technique of using moss for investigation of environmental pollutants was first proposed in 1968 by Åke Rühling and Germund Tyler at Lund University, Sweden.

The method is simple; moss is collected, dried, manually cleaned of debris and other moss species and then analysed for pollutants. By comparing results from different locations, one can obtain an overview of the deposition of pollutants through air and precipitation over the last 2-3 years.

In other words, the moss is a simple and cost-effective sampler for pollution, providing a good estimation of the pollution at a specific location. As mosses are found virtually everywhere, moss is particularly well suited for studies of pollution on both local, regional and European scale if various stations with good geographical distribution are chosen.

EUROPEAN MOSS SURVEY

ICP Vegetation is a long-running, coordinated European biomonitoring programme. It uses mosses to map atmospheric deposition of pollutants across roughly 25-35 countries every five years.

The project focuses on heavy metals, nitrogen, persistent organic pollutants (POPs/POP-like substances) and, more recently, microplastics, using harmonised field and analytical protocols.

NATIONAL MONITORING PROGRAMME

From 1987 until 2015 Norway had a national moss survey programme. This was a collaboration between the Norwegian University of Science and Technology (NTNU) in Trondheim and NILU and was led by Dr Eilif Steinnes. The

A single plant of stairstep moss with its characteristic "steps", where one step is added to the plant every year. Steps representing the past 2–3 years are collected and analysed for environmental pollutants. Note that parts of the leaves that are more than three years old have already started to disintegrate. *Photo: Tore Flatlandsmo Berglen / NILU*

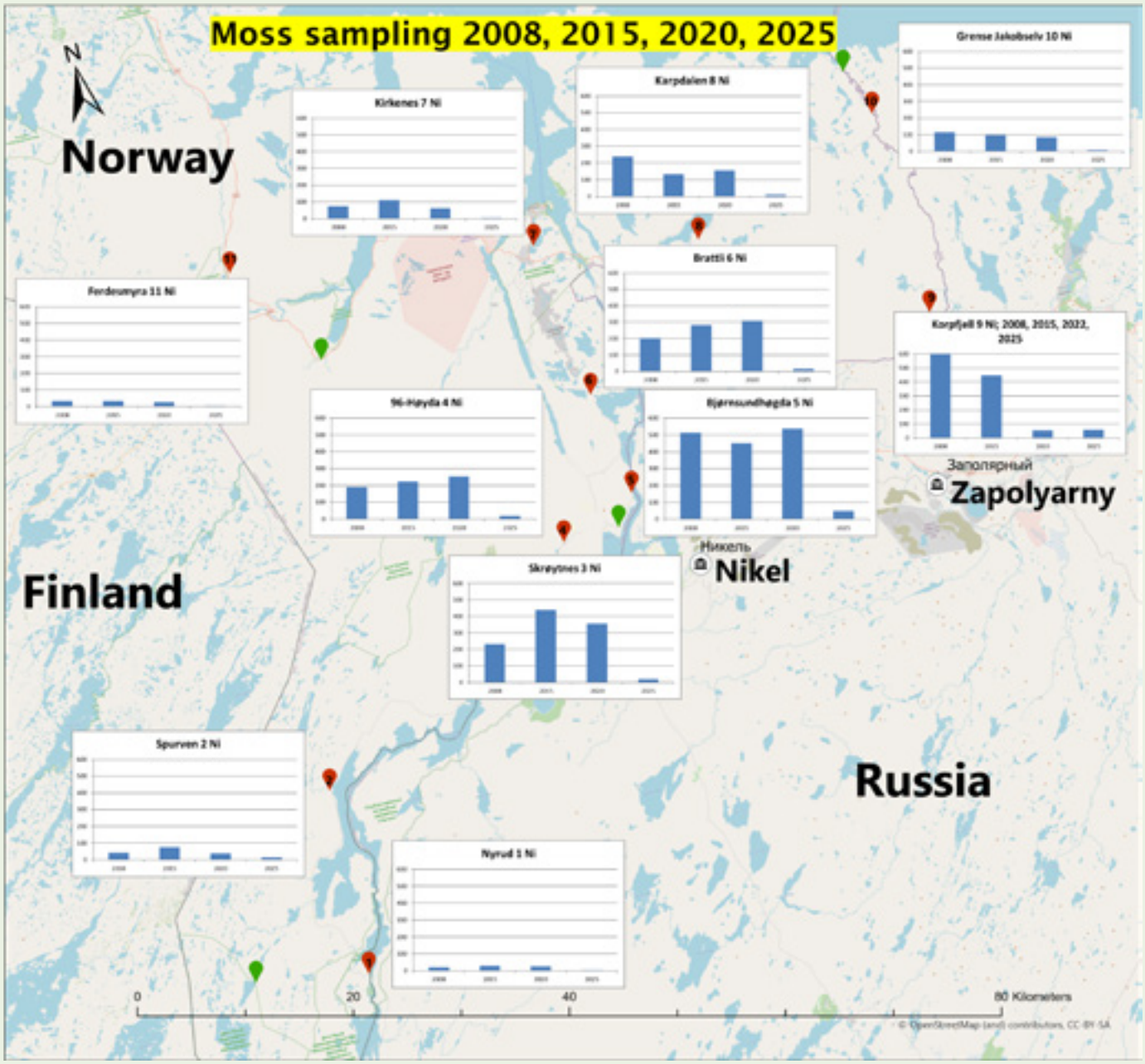
number of stations varied, and in the last study year (2015) stairstep moss was collected from 230 locations and analysed for 56 different elements. Altogether, the moss survey programme constitutes an incredibly valuable time series for inputs of environmental pollutants from 1977, 1985, 1990, 1995, 2000, 2005, 2010 and up to 2015.

The national programme ended due to lack of funding, but the sampling and analysis was repeated for Finnmark County in 2020, and the results were published in ICP's Vegetation report.

In 2025, the Svanhovd branch of the Norwegian Institute of Bioeconomy Research (NIBIO Svanhovd) collected soil samples all over Norway. This tour was part of the monitoring of radioactivity after the nuclear accident in Chernobyl in 1986. The soil stations coincide with the former moss stations, and stairstep moss was collected in Troms and Finnmark Counties for future analysis.

The ICP Vegetation (International Cooperative Programme) is an international research programme investigating the impacts of air pollutants on crops and (semi-)natural vegetation. It reports to the Working Group on Effects of the United Nations Economic Commission for Europe Convention on Long-Range Transboundary Air Pollution. The programme focuses on the impacts of ozone pollution on vegetation and the atmospheric deposition of heavy metals, nitrogen and persistent organic pollutants to vegetation.

https://icpvegetation.ceh.ac.uk



Nickel is a trace metal from smelter activity Zapolyarny / Заполя́рный and Nikel / Никель in northwestern Russia close to the border with Norway. The columns represent results from the 2008, 2015, 2020 and 2025 surveys at eleven Norwegian sampling stations in the border areas. Note the low values upwind from the Russian smelters (Nyrud 1, Spurven 2) and high concentrations at the stations close to Nikel (Skrøytnes 3, 96–Høyda 4, Bjørnsund 5 and Brattli 6), and downwind of Zapolyarny (Korpfjell 9). Note also the sudden decrease between 2020 and 2025 due to the shutdown of the Nikel smelter in December 2020. Unit: µg metal / g dry moss. The maximum value is 600 and the scale is the same in all plots.
Map: © OpenStreetMap, Overlay text and graphs: Tore Flatlandsmo Berglen / NILU

MOSS SAMPLING NEAR INDUSTRIAL SITES

Between 2000 and 2015 NILU and NTNU conducted a moss survey of atmospheric deposition of heavy metals around industrial enterprises in Norway. In 2015, 22 industries located at 17 different sites financed their own participation. During the initial participation, samples were collected from ten measurement points around the industry to obtain a comprehensive picture of the dispersion pattern. In subsequent participations, samples were taken from the five most informative measurement points.

In general, the results showed that deposition of heavy metals close to industrial sites is related to the industrial processes used. The pollution is often deposited locally since the metals are associated with particles.

Akvaplan-niva and NILU have a joint project for Equinor at Hammerfest LNG. Moss is one of the environmental indicators investigated in the project.

BORDER REGION TOWARDS RUSSIA

In 2008, NILU and NIBIO Svanhovd received funding to collect stairstep moss samples from eleven stations along the Norwegian-Russian border. The aim was to investigate contribution from smelter activity in the towns of Zapolyarny and Nikel close to the border, with emphasis on the trace metals nickel, copper, cobalt and arsenic. The prevailing wind direction in the border areas is from the south during winter. The eleven stations were carefully chosen based on meteorology and distance from the smelters; two stations were located upwind of the Russian smelters, four stations were located close to Nikel, two stations were located close to Kirkenes, two stations were located downwind, and one station was used as background.

The sampling was repeated in 2015, 2020 and 2025. The results for nickel clearly illustrate how pollution from the smelters affects the surrounding areas, both close to the smelters and downwind.

The Nikel smelter ceased operation in December 2020, when the production was moved to Monchegorsk, 150 km south of Murmansk. And the moss analysis clearly shows a sudden and abrupt decrease in pollution levels between 2020 and 2025. For the stations close to Nikel, the concentrations of nickel decreased by 90-95% from 2020 to 2025.

THE TAKE-HOME MESSAGE

- Stairstep moss (*Hylocomium splendens*) is a very reliable and cost-effective biomonitor of air pollution, especially for metals.
- Both national and international moss surveys provide long and valuable time series for air pollution, from the 1970s until today.
- Even though the national moss survey stopped in 2015, the sampling continues in the northernmost counties Troms and Finnmark, and along the Russian border.
- The moss sampling programme in the border areas towards Russia shows a sharp decline in the concentrations of nickel, copper, cobalt and arsenic after the Nikel smelter shut down in December 2020. ■

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ACKNOWLEDGEMENT

Funding sources for moss sampling include the Norwegian Environment Agency, the Ministry of Climate and Environment, the Interreg Aurora project *Our Precious Waters* and Equinor Hammerfest LNG, in addition to internal funding from the project partners.

Harald Dag Jølle // Norwegian Polar Institute

Politics and science in Greenland

RETROSPECTIVE

Donald Trump is not the first to set his sights on the vast ice island in the northwest Atlantic. Norway too has an imperialist legacy. And when Norway was vying for control over part of Greenland, scientists played a key role.

During the peace negotiations after the First World War in 1919, the Danish Foreign Minister contacted his Norwegian counterpart, Nils Claus Ihlen. Denmark was soliciting international support for extending its sovereignty to *all of* Greenland, not just the colonies on the west and southeast coasts. In 1916, the United States had consented to Danish control as part of the deal when the US bought the Danish West Indies. Now the Danes wanted to know how Norway would react to their bid for full sovereignty over Greenland. The Norwegian Foreign Minister stated that Norway would not oppose it, as long as Denmark supported Norway's desire for sovereignty over Spitsbergen. Norway attained that goal the following year, when the Spitsbergen Treaty was signed.

In 1921, when the Danes celebrated the bicentenary of the arrival of missionary and coloniser Hans Egede in Greenland, Denmark proclaimed that it had now extended its sovereignty to the entire island. At the same time, they declared that the Danish monopoly, as practised in the colonies on the west coast, would now also apply to the east coast.

Denmark had tried to persuade Norway to endorse Foreign Minister Ihlen's pledge in writing, but the Norwegian authorities had replied that they could not accept an extension of Danish sovereignty if it meant that Norwegians lost the right to hunt and fish in East Greenland. The Danes were not willing to make any such concession and went ahead with their claim, relying on Ihlen's spoken pledge from 1919 as a sufficient guarantee of the Norwegian position.

Some of the men who represented Norway in The Hague in the case Denmark brought against the Norwegian occupation. Seated left to right: historian Oluf Kolsrud, lawyers Helge Klæstad and Gustav Smedal, and leader of the Norwegian Svalbard and Arctic Ocean Survey Adolf Hoel. *Photo: Norwegian Polar Institute*

A SENSE OF HISTORIC INJUSTICE

In Norway, the Danish declaration of sovereignty was widely seen as a provocation. Many Norwegians strongly believed that their country had been shortchanged during the dissolution of the Norwegian–Danish political union in 1814, when the colonies established under the Norwegian–Atlantic empire in the Middle Ages, including Greenland, Iceland and the Faroe Islands, had ended up under Danish control. This was an injustice that some believed had to be rectified by Norway reclaiming the whole of Greenland.

Admittedly, few argued in favour of such radical action. History professor Halvdan Koht asserted, for example, that in the compensation settlement with Denmark in 1821, Norway had accepted that the colonies in West Greenland became Danish. It was unfair, and a bitter pill to swallow, but little could be done about it under international law. On the other hand, East Greenland, according to Koht, was "unoccupied land". But if the Danes insisted on their claim to sovereignty over the whole of Greenland, Koht said, it was undoubtedly Norway that had rights to East Greenland.

Denmark and Norway commenced negotiations on the issue, and Koht, who later became the Norwegian Foreign Minister, was a member of the Danish–Norwegian commission that agreed on an interim solution in 1924: the Norwegians would be permitted to hunt, trap, mine, and engage in other gainful activities in East Greenland for 20 years, until 1944, but must defer settlement of the issue of territorial sovereignty.

This map of Greenland, used during the case in The Hague, shows the part of the east coast over which Norway claimed sovereignty—Eirik Raudes Land. *Map from the archive of the Norwegian Polar Institute*

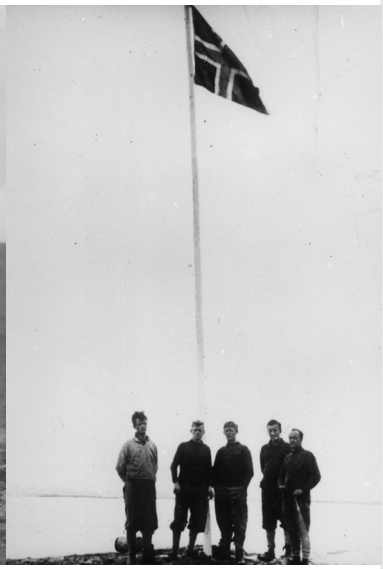
INCREASED RESEARCH ACTIVITY

This temporary and unresolved solution led to both Norway and Denmark stepping up their economic and scientific activity on the northeast coast of Greenland.

In 1924, for example, the Danish polar explorer Ejnar Mikkelsen led a relocation operation in which seventy men, women, and children from Ammassalik in Southeast Greenland emigrated 1,000 kilometres further north, to the area that Norwegians had declared uninhabited. In fact, there had long been plans to establish a colony at the mouth of the Scoresbysund fjord, but the sudden implementation of those plans was undoubtedly a direct consequence of the dispute with Norway, and the Danes' desire to demonstrate their sovereignty.

Norway, for its part, launched annual research expeditions to Northeast Greenland, which from 1928 were organised by the newly established Norwegian Svalbard and Arctic Ocean Survey (the forerunner of the Norwegian Polar Institute), led by Adolf Hoel. At the same time, several hunting

Building trapper's cabins was an efficient way to demonstrate that an area was being used by Norwegians. This image shows the cabin at Kap Herschell, built by members of the Hird expedition in 1927. *Photo: Norwegian Polar Institute*



The Norwegian flag flies in Myggbukta 27 June 1931, signalling that Eirik Raudes Land has been occupied. Trappers left to right: Hallvard Devold, Eiliv Herdal, Ingvald Strøm, Søren Richter and Thor Halle. *Photo: Norwegian Polar Institute*

and trapping expeditions were equipped to winter on Greenland. The Geophysical Institute in Tromsø maintained the manned meteorological station in Myggbukta, which had been set up in 1922. And in 1929, Norway founded its own trading company for East Greenland. Denmark did likewise.

In 1930, Norway's Svalbard and Arctic Ocean Council advocated that Norway should occupy the part of East Greenland that they considered a no-man's land, or, to use the imperialist term, a *terra nullius*. The government did not agree to this, but gave three people (one of whom was Adolf Hoel) police authority over the Norwegians staying in the area. Shortly afterwards, it became known that Denmark would be sending the renowned polar researcher and geologist Lauge Koch northward at the head of an ambitious three-year scientific expedition. This major Danish initiative made Norwegian Greenland agitators and scientists nervous. They feared that a large-scale expedition would underscore Denmark's interests in the territory, giving the Danes a significant advantage in the court case that many believed would be needed to settle the issue of sovereignty. But despite strong exhortations, the Norwegian government stood by its decision not to occupy any territory.

But now the patience of the Norwegian agitators led by Hoel was running out. They were not going to stand by and watch Denmark claim what they believed was Norwegian territory. To put further pressure on the government, they sent a coded telegram to Myggbukta. As a result, on 27 June 1931, five Norwegian trappers occupied a tract of land north of Scoresbysund.

ERIK THE RED'S LAND

The actual occupation amounted to no more than the men exiting their cabin to raise the Norwegian flag and remove their hats. Using a string attached to the camera, they took a selfie so that all five occupiers would be included in the photo. They then went back into the station and signed a declaration that translates as: "On this day, at 5 pm, we raised the Norwegian flag and took possession of the territory from the Carlsberg Fjord in the south to the Besselfjord in the north in the name of HM King Haakon VII, and called it Erik the Red's Land." The declaration was telegraphed to a number of Norwegian newspapers.

The legendary trapper Henri Rudi from Tromsø had spent 20 winters in Svalbard before he arrived in Greenland in 1928. He was enthralled by the magnificent landscape: "Svalbard is nothing compared to this; everything here is on a infinitely grander scale." *Photo: Norwegian Polar Institute*

This was a big event for the five winter trappers, but there was little revelry in Myggbukta. The two-year expedition was almost at an end, and they had run out of every kind of treat. Even coffee. The telegram from Myggbukta sparked a heated debate back in Norway. But this pressure gambit undoubtedly had the intended effect. A fortnight later, on 10 June 1931, the government went ahead with a formal occupation of the defined territory. The following day, Denmark took Norway to the Permanent Court of International Justice in The Hague.

THE TRIAL IN THE HAGUE

Norway asserted that the occupation was valid under international law. Its case for this was essentially as follows: By 1814, the west coast of Greenland had been colonised from the southern tip to 73 degrees north. In 1894, the colony of Angmagssalik on the southeast coast was included, and by 1905, Danish rule on the west coast had been extended north to 74° 30'. "Apart from that: No Danish colonisation", as it was worded in a memo for the proceedings in The Hague. According to the Norwegian lawyers who argued the case, any territory that *was not* colonised counted as *terra nullius*. They asserted that this was widely accepted. Otherwise, they asked rhetorically, why would Denmark have embarked on its diplomatic campaign in 1916 to have an extension of sovereignty recognised? Further, they asserted that what Foreign Minister Ihlen had said could not be construed as anything more than an "offhand comment". At the same time, they claimed that the Danes had acted unfairly by not informing Norway that they would extend their monopoly to the east coast as well.

From the Norwegian point of view, the occupation was therefore not only justified, it was also *necessary*; the issue of sovereignty had not been resolved in the East Greenland Agreement of 1924, and the territory could not continue to be a *terra nullius* "because then the dispute would become permanent". A Norwegian occupation was also essential in preventing Lauge Koch's expedition from resulting in Danish occupation. In other words, it was emphasised, the Norwegian action was the only way to secure Norwegian trapping interests for the future.

However, the arguments were not compelling enough to convince the judges in The Hague, who handed down their verdict on 5 April 1933. On that same day, a telegram arrived at the Antarctichavn trapping station on the east coast of Greenland, where the famous trapper, author, and lawyer Helge Ingstad had held sway as Norwegian governor since 1932. It read: "Norway lost the Greenland case before The Hague Tribunal on all counts."

Adolf Hoel and Anders Orvin prepare to stake a claim in East Greenland 25 July 1930. The sign they are painting reads: "The land around K Stosch is this day annexed by A/S Arktisk Næringsdrift, Oslo, for exploitation of the coal deposits." *Photo: Norwegian Polar Institute*

Norway lost the case in The Hague in 1933, but the East Greenland Agreement from 1924 allowed Norwegians to continue with various kinds of commercial ventures until 1944. In this photo, Henry Rudi and Schjølberg Nilsen are being visited by geologist Brit Hofseth, who participated in a expedition on board Polarbjørn in 1939. *Photo: Norwegian Polar Institute*

INTERPRETING THE GREENLAND ISSUE

What was the Norwegian policy on Greenland an expression of? Should we view Norway as an aggressor against a neighbouring country? Or should we see both the Danish and Norwegian actions as two imperialist states seeking to deprive the Greenlanders of their land? And was the Norwegian position that this coast was uninhabited and thus a *terra nullius* any more unreasonable than the Danes' alleged right to roll out colonial rule to the whole of Greenland?

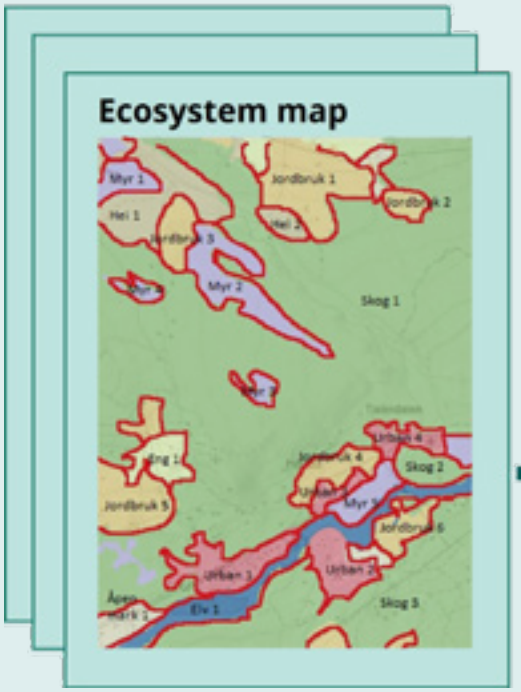
I will refrain from passing judgement on who was right in this dispute. The judges in The Hague did that in 1933. My point is that the Greenland case was not as extraordinary as was subsequently claimed. The leading Norwegian international law experts at the time asserted that Norway had the right to occupy the disputed territory, and up until the occupation, Norway had largely followed the same procedure as in Svalbard, Jan Mayen, and Antarctica, and attempted to follow in Franz Josef Land. This confluence of science, politics and trade has often been characterised as *Arctic imperialism*, a strategy for which Adolf Hoel provided the following formula: "The first tactic is to send out research expeditions." The second is to establish "scientific and humanitarian stations and facilities such as meteorological stations". Next, Hoel believed it was important to encourage and support "economic enterprises". Finally, one should "campaign at home and abroad in order to promote one's goals, which should then be promoted as endeavours for the country's progress".

The extraordinary aspect of the Greenland case in the history of Norwegian polar politics is that a private occupation led to a formal occupation, which then ended up in The Hague for a final ruling. ■

Carl William Lund, Noortje Dijkstra Haugstvedt and Kathrin Bögelsack
// Norwegian Mapping Authority

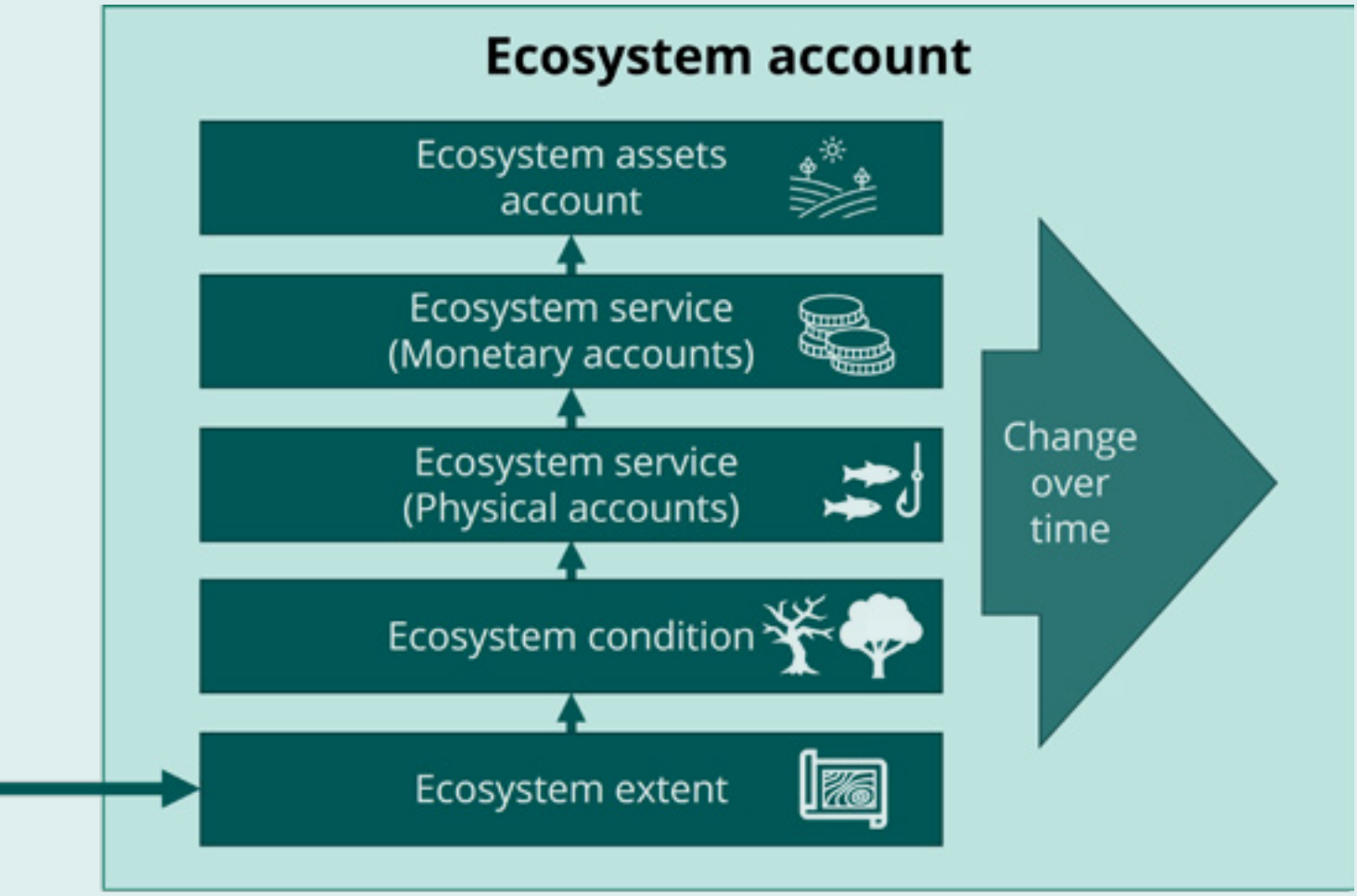
Mapping Norway's marine ecosystems: a puzzle with missing pieces

RESEARCH NOTES



How healthy are Norway's marine ecosystems? To answer the question, we need a marine ecosystem account that gives an overview of the ecosystems, their condition, and the services they provide. This helps decision-makers manage marine resources more sustainably and safeguard Norway's marine areas.

THE EUROPEAN UNION RECENTLY INTRODUCED a regulation requiring member countries to report on the state of nature, including the extent of marine areas. Ecosystem accounting is one way to do that. Norway must be ready and actively participate in shaping the process. We explored how existing data can be combined to create digital maps of Norwegian marine ecosystems. The goal? Make the best possible use of what we already know, while identifying gaps that prevent us from seeing the full picture.



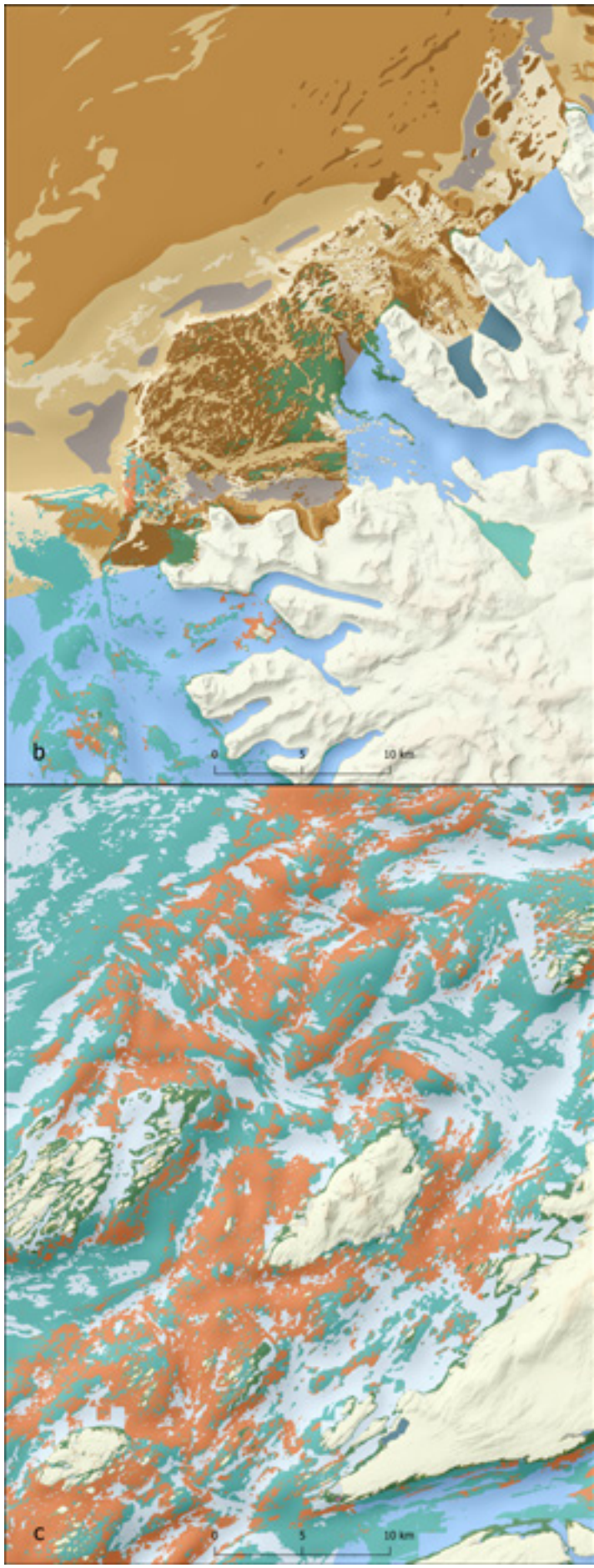
Marine ecosystem accounting is a structured approach to measuring the extent, condition, and economic value of ocean and coastal ecosystems. It combines data on habitats, species, ecosystem health, and the services these systems provide, including fisheries, coastal protection, carbon sequestration, and recreation. By linking this to social and economic data, ecosystem accounting allows us to quantify the ocean's contributions to society and track how human activities affect marine nature.
Figure: Norwegian Environment Agency

UNEVEN DATA COVERAGE

We started by reviewing more than 100 available datasets, including raw, processed, and modelled data on depth, substrate, geomorphology, water temperature, salinity, turbidity, and species distribution plus satellite data. Data on human impacts such as pollution, seabed disturbance, and resource extraction are also required and essential for understanding how human activities influence ecosystem conditions and consequently ecosystem services.

The results show a good starting point, but far from a complete picture. Data coverage is uneven, and many areas have only been mapped once, limiting the ability to track changes over time. Coarse datasets have better coverage than detailed ones but provide less precision. Essential data for modelling species distributions, such as seabed substrate and bathymetry, are lacking for large areas. Vital habitats for invertebrates, such as maerl beds, remain largely unmapped.

Data accessibility is another challenge. Many relevant datasets are not easily available through national portals like Geonorge. Multiple versions of datasets exist; many datasets lack quality standards, and metadata essential for integration and reuse is absent. For example, information on survey coverage is often missing, limiting confidence in the data.



Map of ecosystem types in the pilot area (a). Map section (b) shows smaller units such as bays and lagoons, but also how several ecosystem types overlap substrate information in the background. This is also evident in (c), where there is a large overlap between coral reefs and sponge gardens, while the kelp forest occurs in shallower water as a thin belt along the coast. *Map: Kathrin Bögelsack and Ådne Brandtzæg / Norwegian Mapping Authority*

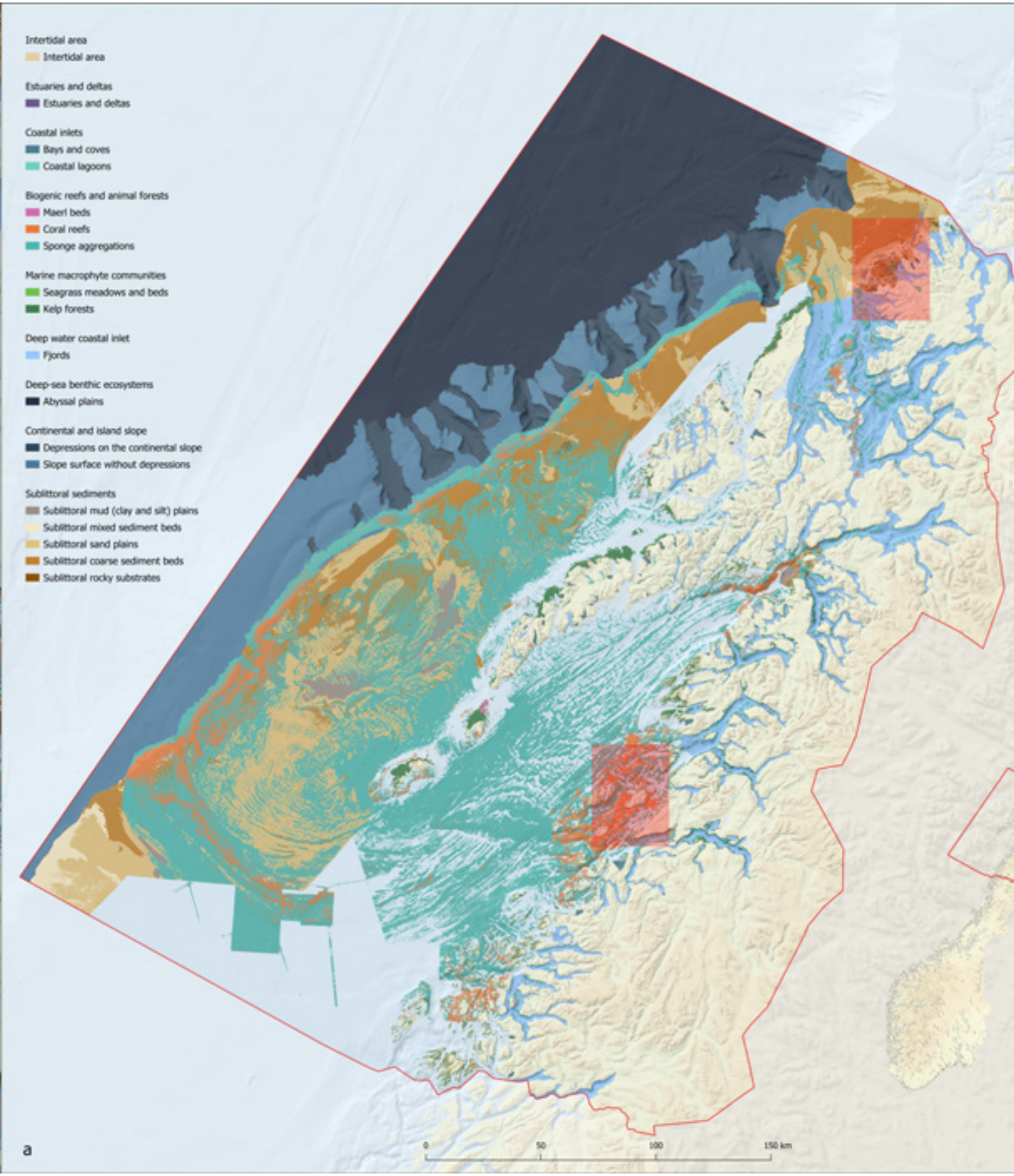

Intertidal area
Intertidal area
Estuaries and deltas
Estuaries and deltas
Coastal inlets
Bays and coves
Coastal lagoons
Biogenic reefs and animal forests
Maerl beds
Coral reefs
Sponge aggregations
Marine macrophyte communities
Seagrass meadows and beds
Kelp forests
Deep water coastal inlet
Fjords
Deep-sea benthic ecosystems
Abyssal plains
Continental and island slope
Depressions on the continental slope
Slope surface without depressions
Sublittoral sediments
Sublittoral mud (clay and silt) plains
Sublittoral mixed sediment beds
Sublittoral sand plains
Sublittoral coarse sediment beds
Sublittoral rocky substrates
0
50
100
150 km
a

Illustration of the nature in Lofoten viewed as a mesh. A mesh is a 3D surface created by combining an orthophoto with a height model. *Image: Norwegian Mapping Authority and Geodata AS*

ECOSYSTEM CLASSIFICATION CHALLENGES

Ecosystem accounting depends not only on accurate and accessible data, but also on a well-defined ecosystem typology. This ensures consistent classification, mapping, and reporting of ecosystem extent, conditions and services. EU's typology is not always suitable for Norwegian conditions. Norway lacks a solution for sea ice reporting, and its coastline, with inlets, fjords, bays, and coastal archipelagos, is far more complex than that of many European countries. The limited definitions of these coastal landforms make their application to the Norwegian coast difficult. Developing such definitions and adapting EU's typology for national reporting is an important task.

IT STARTS WITH LOVE

Despite these challenges, progress is being made. A national pilot for marine ecosystem accounting was launched around Lofoten, including Vesterålen (LoVe), a coastal zone classed as "particularly valuable and vulnerable". Digital ecosystem maps for the pilot area are under development to explore their potential for Norwegian marine management. The pilot will strengthen Norway's ability to contribute to and influence international frameworks and requirements.

Robust ecosystem accounts serve as important decision-making tools for sustainable ocean management. They help monitor vulnerable areas,

track changes in ecosystem extent, and assess the impacts of human activities. To succeed, we must fill the gaps and keep assembling the puzzle, until we see the full picture of Norway's marine ecosystems.

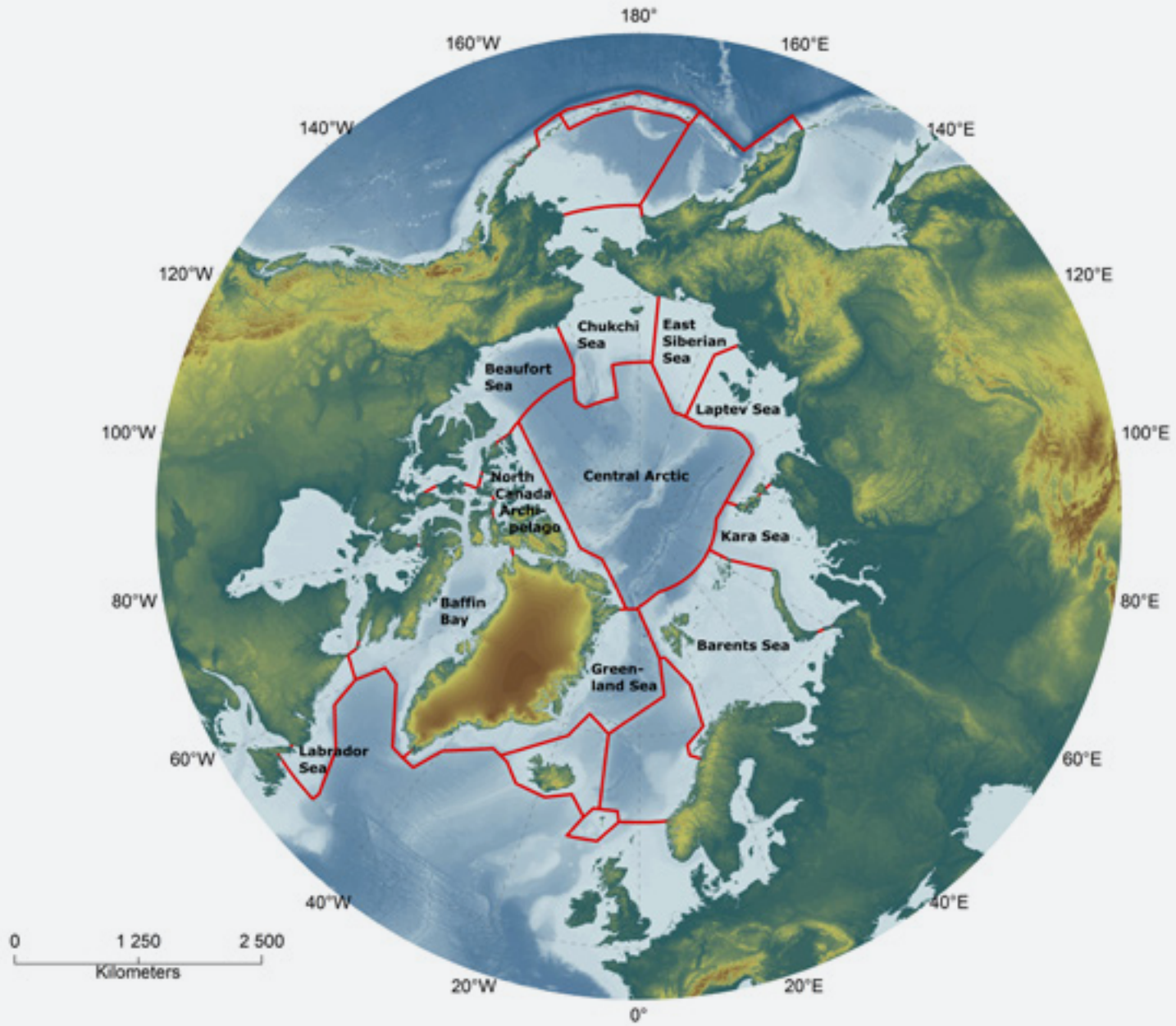
ACKNOWLEDGEMENTS:

The project is funded by the Norwegian Environment Agency and is a collaboration between the Norwegian Mapping Authority, the Institute of Marine Research, the Geological Survey of Norway, the Norwegian Institute for Water Research, the Norwegian Institute for Nature Research, the Directorate of Fisheries, and Statistics Norway. ■

FURTHER READING:

Eurostat, an official EU website (2025) Ecosystem accounts – measuring the contribution of nature to the economy and human wellbeing. *https://ec.europa.eu/eurostat/statistics-explained/* Search for "ecosystem accounts".

Norwegian government White Paper (2021) Meld. St. 29 (2020–2021) Norway's integrated plan for the conservation of areas of special importance for marine biodiversity. *https://www.regjeringen.no/en/find-document/white-papers-/id1754/* Search for "marine biodiversity" and limit the time period to 2020–2021. Chapter 2 of this document describes "particularly valuable and vulnerable areas" in Norway.



High-Arctic sea areas defined as Large Marine Ecosystems. LMEs shown here with names correspond to those presented in the other graphs.
Map: Protection of the Arctic Marine Environment (PAME) / Arctic Council

Gunnar Sander // Norwegian Institute for Water Research
Eirik Mikkelsen // Nofima

Ship traffic is growing in the High Arctic, but very unevenly

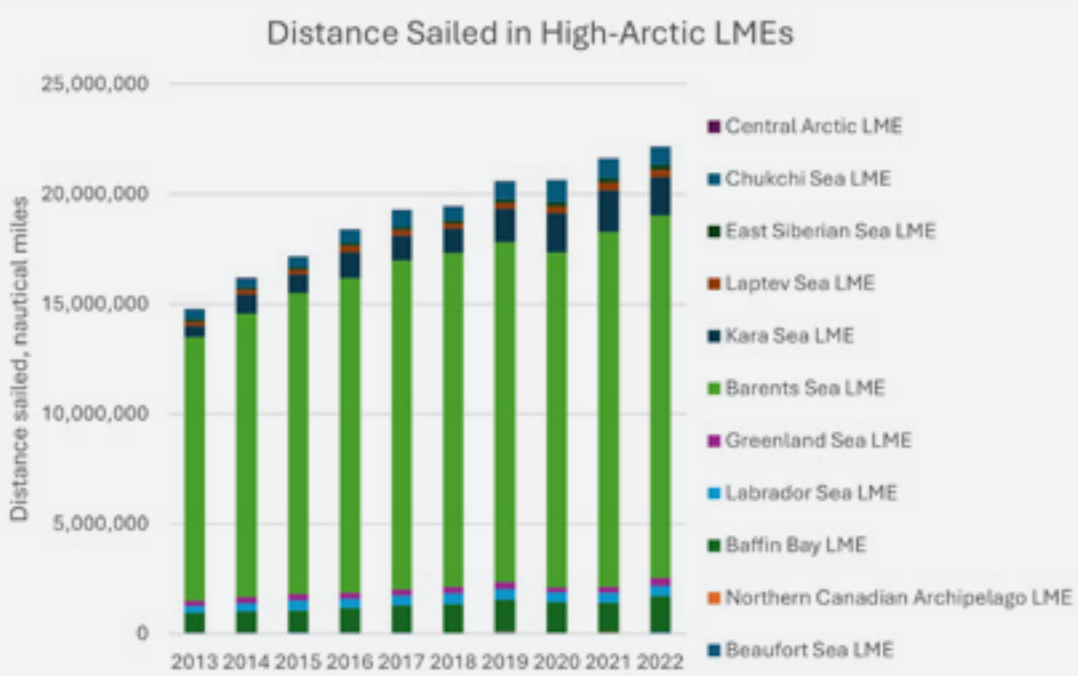
RESEARCH NOTES

Ship traffic in the High Arctic grew between 2013 and 2022. There are huge differences between different Arctic seas in terms of total activity, growth rates, seasonal variation and types of vessels.

Signals from Automatic Identification System (AIS) transmitters on ships generate huge datasets that have revolutionised the ability to analyse ship traffic. The Arctic Council has developed the Arctic Ship Traffic Database (ASTD), building on a system from the Norwegian Coastal Administration (Kystverket). This offers the general user many options for generating statistics for traffic in areas, over crossing lines, and in ports. The core of these geographical definitions is a heritage from work by the authors of this article arising from a collaboration between the Coastal Administration and the Fram Centre. In an analysis of traffic patterns for the first decade of ASTD operations, we have both tested the utility of the system and provided an analysis of traffic developments.

It is a common assumption that reduced sea-ice cover will increase ship traffic. Finding out how much the traffic grows, however, depends on geographical definitions. A very relevant delimitation is the area of the International Maritime Organization's Polar Code, which addresses the peculiar challenges for ships operating near the poles. Within its Arctic boundary, the distance sailed by ships increased from 6.1 million nautical miles (nm) per year in 2013 to 12.1 million nm in 2022, equivalent to 8.7% average annual growth.

Unfortunately, it is not possible to analyse the huge internal differences within the Polar Code area since there is no agreed definition of how it can be subdivided. To understand spatial variability, we were confined to comparing traffic in



Ship traffic in High-Arctic Large Marine Ecosystems (LMEs), total distance in nautical miles. *Graph: Eirik Mikkelsen / Nofima*

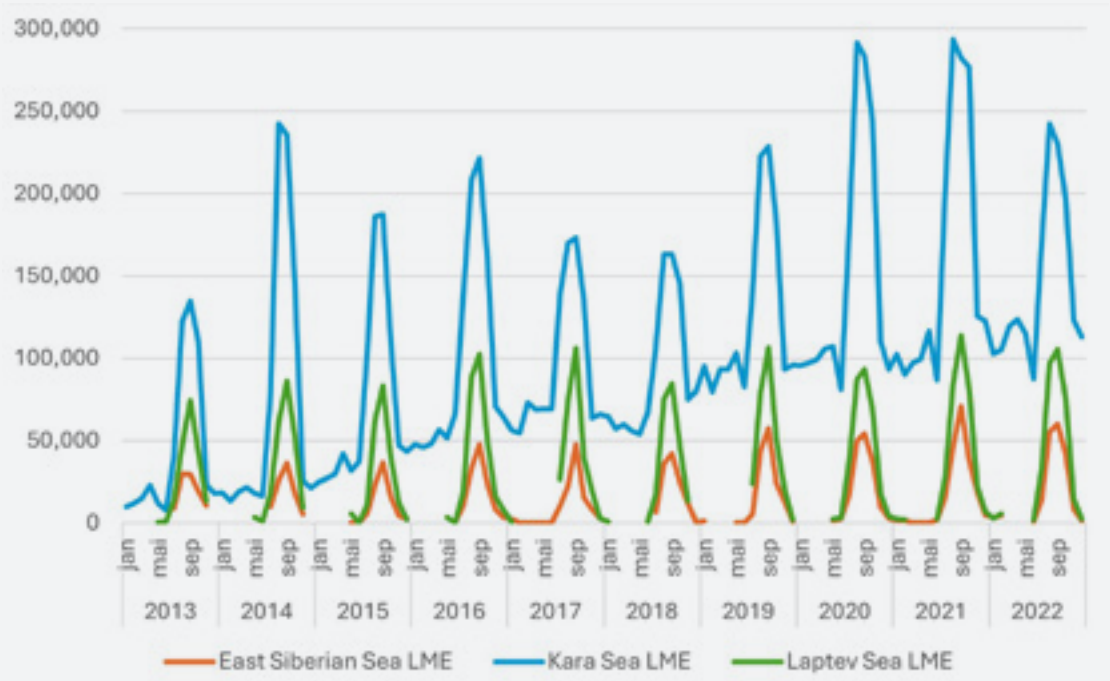
High-Arctic Large Marine Ecosystems (LMEs). When LMEs are used, areas south of the boundary of the Polar Code are included, which is why the total traffic we show here is 22.2 million nm in 2022, nearly twice as much as in the Polar Code area.

Vessels in the Barents Sea accounted for 74% of the total distance sailed in the High-Arctic LMEs in 2022. At the opposite end, the traffic in the Northern Canadian Archipelago was lowest with 0.01% of the total, while the Central Arctic Ocean had a 0.1% share.

Over the decade 2013-2022, traffic has grown in all the LMEs, but very unequally. In the Barents Sea, vessels sailed 4.5 million nm further in 2022 than 10 years before, making the growth there the largest. As a contrast, the traffic in the Northern Canadian Archipelago increased by only 0.002 million nm. The traffic in the Central Arctic Ocean also grew, but was primarily characterised by large variation between years. A remarkable change was the tripling of the sailed distance in the Kara Sea, making this LME number two in 2022 traffic with a 7.8% share of the distance sailed, slightly before Baffin Bay with 7.3%.

Looking into the types of vessels that operate gives an indication of what types of activities create the traffic. It also gives a first indication of the impacts and risks involved. To understand this in depth, data on traffic need to be supplemented with knowledge on, for instance, emissions, catches, and risks of accidents involving people (cruise ships) or creating large-scale pollution (oil tankers).

The type of traffic in the various regions also varies considerably. In the Barents Sea, fishing vessels constitute such a big part of the traffic that fishing vessels become the dominating ship type for all the High-Arctic LMEs. Fisheries are important in Baffin Bay too. There, the traffic also contains a significant proportion of medium-sized container vessels that serve the settlements in Greenland and northern Canada, and larger bulk carriers that transport iron-ore from a big mine on Baffin Island, which opened in 2015. In the Kara Sea, there has been steady growth in traffic with cargo ships. Such vessels are important in delivering goods and equipment for the construction of oil and gas projects, with related infrastructure. The development of large-scale petroleum projects on the Yamal Peninsula has been followed by the



Nautical miles sailed per month in three Large Marine Ecosystems (LMEs) north of Russia. The growth of traffic in the Kara Sea, even in the winter months, is exceptional. *Graph: Eirik Mikkelsen / Nofima*

introduction of crude oil and gas tankers of a size and type that had never been present in the Arctic before. There are low shares of fishing vessels, cruise vessels and container ships north of Russia.

For ship traffic in the Arctic to grow substantially, there is a need to overcome the barriers created by winter conditions. Despite climate change, the traffic is still highly seasonal, concentrated to a few summer months, dropping in winter to almost zero in the areas with harshest climate. Again, the Kara Sea is a remarkable exception. The Russians have upgraded their fleet of icebreakers and supporting infrastructure, and the fleet of ships transporting oil and gas are ice-classed.

A major reason for the public and political interest in Arctic shipping lies in the vision of the Arctic becoming a corridor for intercontinental traffic, primarily between Europe and Asia. The ASTD can only give some clues, indicating few transits. Other sources can tell that even before the Western sanctions following Russia's full-scale attack on Ukraine, the transit traffic through Russia's Northern Sea Route was lower than one day's traffic in the Suez Canal. It dropped from 85 transit voyages in 2021 to 43 in 2022, most likely because of the sanctions. As long as the war and the sanctions continue, it is unlikely that Western ships will engage in transit traffic through Russian waters.

Intercontinental shipping therefore seems to be an unrealistic driver for the growth of Arctic shipping for the near future. Despite this, our analysis illustrates that all kinds of economic activities within the Arctic can create growth in shipping, either internally in the Arctic, or between Arctic destinations and ports outside the Arctic. ■

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Sander G, Mikkelsen E (2025) Arctic shipping 2013–2022: the traffic has grown, with big variation between regions, seasons and ship types. Polar Research 44, *https://doi.org/10.33265/polar.v44.10978*

About the Arctic Ship Traffic Database: *https://arctic-council.org/projects/arctic-ship-traffic-data-astd/*

Ellen Kathrine Bludd // UiT The Arctic University of Norway
Karine Nigar Aarskog*// Norwegian Polar Institute

Why is it important to use Sami place names?

SCIENCE AND SOCIETY

Vast open territories in the Arctic have been claimed and named as though they were blank white pieces of canvas. But the Indigenous place names that existed long before these new names were invented carry history, culture, and identity.

"INDIGENOUS PLACE NAMES HOLD SIGNIFICANCE BEYOND mere geographical labels; they embody a vibrant tradition that ties communities to their environment. Still, through a history of colonialism these names have been replaced, removed and wrongfully translated on maps," says Ekaterina Mikhailova, associate professor in border studies at UiT The Arctic University of Norway.

*Also affiliated with UiT The Arctic University of Norway

Photograph taken at Håkøya, Tromsø, circa 1890. *Photo: JJ Wickstrøm*

She believes restoring Indigenous place names on maps and in everyday language is an important step toward social justice.

NAMING AS AN EXERCISE OF POWER

"Naming is never a neutral act; it is always political and related to power," states Mikhailova.

She explains that whether it is a ruling elite, a privileged class, a king, or a dictator, certain social groups and individuals exercise the authority to name places in accordance with their values, while others do not.

Hence, the disparity of power is replicated in the space around us.

"Colonial cartographic traditions saw new lands as *terra nullius*, a place void of history and culture that is 'waiting' to be named and mapped," says Ekaterina Mikhailova.

She clarifies that such colonial mapping of territories erased Indigenous place names, and with them the connection between Indigenous peoples and their lands, from both maps and collective memory, contributing to the marginalisation of Indigenous peoples and their cultures.

Mikhailova gives the example of *Cambridge Bay* in Nunavut, Canada. This name was given by British and Canadian explorers in the 1880s and does not reflect the area's history or its significance to the original inhabitants.

"The original name, *Iqaluktuuttiaq*, means 'the good fishing place' and tells a completely different story–a story about the landscape, resources, and the people who have known and used these lands for generations," says Mikhailova.

We can find similar examples across the Arctic.

NAMES EVOKE LANDSCAPES AND LAND USE

Lene Antonsen, professor of Sami language at UiT explains how Sami place names in Sápmi, in northern Scandinavia have been created:

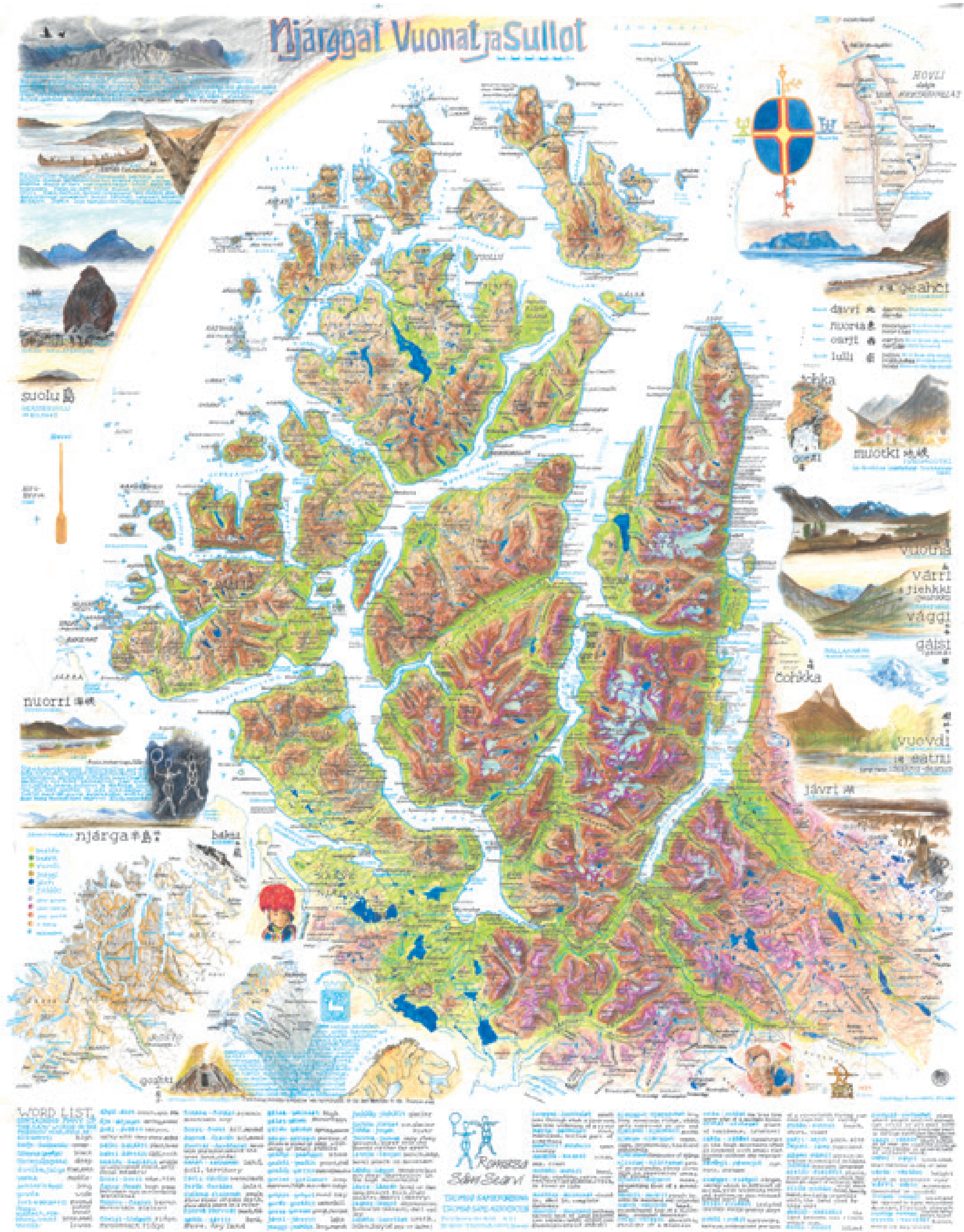
"Typical of Sami place names is that they speak of the natural landscape of the location, or about the use of the land. Many names speak about hunting, fishing, berry picking, travel, reindeer herding and livestock farming. Some names speak of people who have had a connection to that specific location. Other names originate from spirituality and mythology."

There are several Sami languages, which is also reflected in the place names.

"Some names are incomprehensible today and are interpreted as remnants of languages that were spoken in the area before a language shift to Sami occurred," Antonsen explains.

"Indigenous place names exist as a system in which the names relate to each other as a chain of experiences and stories. Passed orally from generation to generation over hundreds of years, Indigenous place names serve as a vital aid for wayfinding and the transfer of accumulated knowledge," Ekaterina Mikhailova explains.

Njárggat Vuonat ja Sullot. Artist Hans Ragnar Mathisen has been creating Sami maps since 1974. The maps are artistically designed, and all names are in Sami. Through his art, Mathisen has contributed to ensuring that Sami place names have been preserved and placed correctly on maps. *Map: Hans Ragnar Mathisen*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várri
vággi
gáisi
čohkka
vuovdi
eatnu
jávri
WORD LIST
Romssa Sámi Searvi

NORWEGIANISATION OF SAMI NAMES

In Norway, the government had a Norwegianisation policy against the Sami and Kven people from the 1850s to around 1963. During this period there was an active attempt to remove Sami place names from public use. An 1876 land sale regulation required properties to have Norwegian names, with Sami or Kven names in parentheses. Later, the Norwegian Geographical Survey translated Sami names into Norwegian if a Norwegian name did not exist.

This practice had consequences for the Sami names on land maps, where place names were Norwegianised—often with incorrect translations. Where both Sami and Norwegian names were in use, as a rule only the Norwegian name was to be included on the map.

In 1937, the policy shifted to require that Sami names be included on maps. Finally, a 1990 law mandated that Sami and Kven place names must be used publicly on maps, signs, and registers, either alone or alongside Norwegian names.

IMPORTANT TO USE SAMI NAMES TODAY

“Some places only have Sami names, especially in the wilderness. Thus, it would be a falsification of the history of the location if one starts replacing a Sami name with a newly created Norwegian name,” says Lene Antonsen.

She explains that where parallel Sami and Norwegian names exist, it is important that the Sami names are visible, on maps, signs, and in databases. This to show equality between the languages, but also to prevent the names from being forgotten.

Sami speakers are a minority, except in inner Finnmark, the northernmost county. In some areas, the Sami language has almost disappeared, and especially in these areas the Sami names function as important cultural heritage.

“The Sami place names speak of the Sami language that has been used in the area. Additionally, they can be a motivation for those who want to learn the language,” Antonsen says.

Sometimes Sami and Norwegian names have completely different meanings, and thus the two names together will explain more about a location than just the Norwegian name alone. This in turn has great cultural-historical value.

Many Norwegian names are phonetic adaptations of the Sami name, and if the Sami name is visible on maps and signs, one understands how the Norwegian name came about.

"But most importantly," Antonsen says, "Norway has recognised Sami languages as equal languages and Indigenous languages, and this also applies to Sami place names. Sami names cannot be silenced."

RESTORING INDIGENOUS PLACE NAMES

"Indigenous place names are often rooted in experiences, sensory impressions, and deep knowledge of the landscape. They offer a window onto a different worldview, a different relationship between nature and humans: one of coexistence, where humans are part of nature rather than being superior to nature," Ekaterina Mikhailova explains.

Bringing back these names is therefore an important step to take for social justice.

"Having Indigenous place names on the map is visibility, recognition, and challenging colonial power structures that still shape society," she says.

"However, bringing Indigenous place names into active use is not easy. Indigenous place names are often in languages that are unfamiliar to the majority population."

This can make it difficult to integrate them into everyday language and maps.

Mikhailova presents a potential solution: develop interactive maps where the names are explained with their meanings and histories. This can help bridge cultural divides and increase understanding of Indigenous perspectives.

INVISIBLE SAMI LANGUAGE

"Sami language has been quite invisible to Norwegian speakers. For those who have grown up with only Norwegian place names, Sami names may be unfamiliar and may alter their perception of the place," says Lene Antonsen.

The visibility of the Sami names on signs also gives status to Sami languages.

"For some of those who do not speak Sami, this may arouse curiosity, they may want to know more about the names and the language," says Antonsen. "But for others this may be provocative," she continues, and explains that Sami language thus gains a status that contradicts what they have learned through their upbringing.

"I also believe that part of the reason is that the Sami language has been exclusive to Sami people and not a national language. Thus, knowledge of the language is very low among Norwegian speakers," says Lene Antonsen.

Most Norwegian-speakers haven't learned about Sami languages at school, and all use of Sami has been suppressed, even for everyday communication such as greetings.

Ekaterina Mikhailova maintains that the current path to reclaiming Indigenous place names is a vivid testimony that these place names are not just a part of the past; they are a key to understanding the present and shaping the future.

"By reintroducing and valuing these names, we can help create a society that is more just, inclusive, and respectful of those who came before us," she says.

Ekaterina Mikhailova concludes with a call to action: "Learning Indigenous place names is a way to orient oneself, not just geographically but also culturally and historically. It is a way to challenge colonial power structures and contribute to a more just and inclusive world." ■

Karley Campbell, Anne Braakmann-Folgmann, Zoe Koenig, Christien Laber, Rosalie McKay and Catherine Taelman // UiT The Arctic University of Norway
Polona Itkin and Megan Lenss // Norwegian Polar Institute
Michele Fabris and Luca Morelli // University of Southern Denmark
Janina Osanen // Norwegian University of Science and Technology
Benjamin Lange // Norwegian Geotechnical Institute

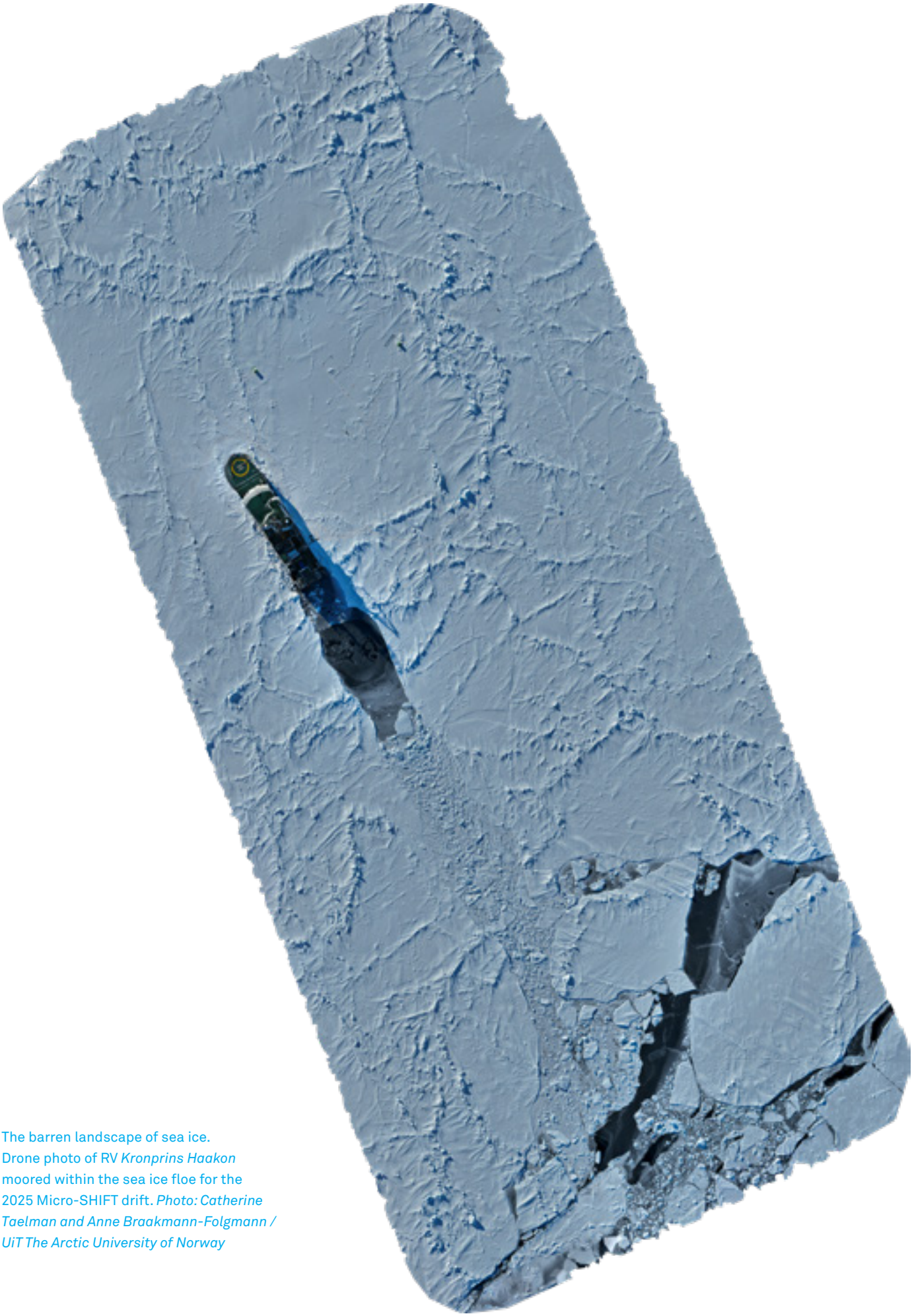
Tending the hidden gardens of the frozen Arctic Ocean

RESEARCH NOTES

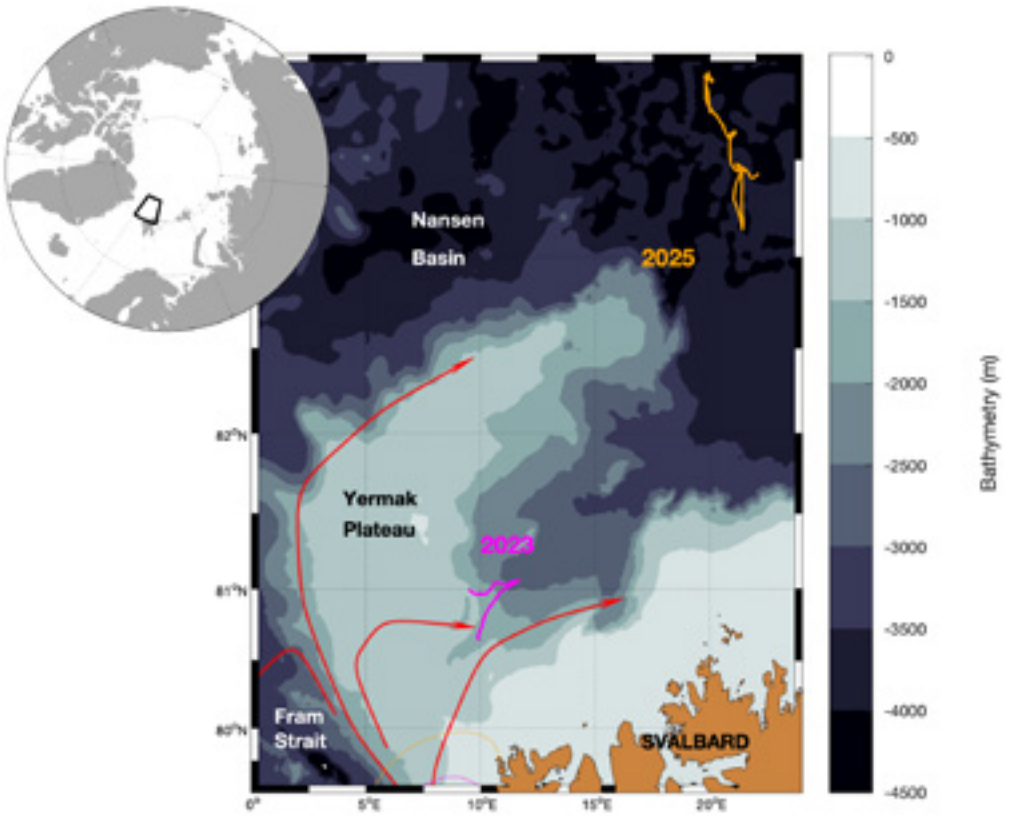
The algae that live in sea ice support life across the Arctic Ocean. But how will their frozen world respond to the warming climate? Drift studies aboard the RV *Kronprins Haakon* help us find the answer.

Sea ice blanketing the Arctic Ocean seems a barren place but look closer–much closer–and you will find a thriving world of microorganisms. The uniquely adapted algae of sea ice perform photosynthesis, and in doing so, produce compounds that feed aquatic life, from swimming zooplankton and ultimately to the mighty polar bear. But sea ice is a dynamic landscape. It is a combination of snow, ice and liquid brine that responds to seasonal warming and the conditions of the ocean below it. This has made it difficult to understand the complex relationships between ice algae and their environment. At the same time, amplified global warming in the Arctic is rapidly changing the icescape. So, what is the future of ice algae in the Arctic marine ecosystem?

This question has been at the centre of the projects BREATHE (Bottom sea ice Respiration and nutrient Exchanges Assessed for THE Arctic) and Micro-SHIFT (Microbial life of Sea ice Habitats Investigated for The Arctic), led by Karley Campbell at UiT The Arctic University of Norway. Together with other sea-ice-focused colleagues, she has completed the first drift studies of RV *Kronprins Haakon* to help provide answers.



The barren landscape of sea ice. Drone photo of RV *Kronprins Haakon* moored within the sea ice floe for the 2025 Micro-SHIFT drift. *Photo: Catherine Taelman and Anne Braakmann-Folgmann / UiT The Arctic University of Norway*



Locations of the 2023 BREATHE (pink) and 2025 Micro-SHIFT (orange) drift tracks on RV *Kronprins Haakon*. *Map: Zoe Koenig / UiT The Arctic University of Norway*

DRIFTING FOR ANSWERS ABOUT SEA ICE

"In a drift you attach the ship to a single ice floe and essentially let nature decide where you will go," says Campbell.

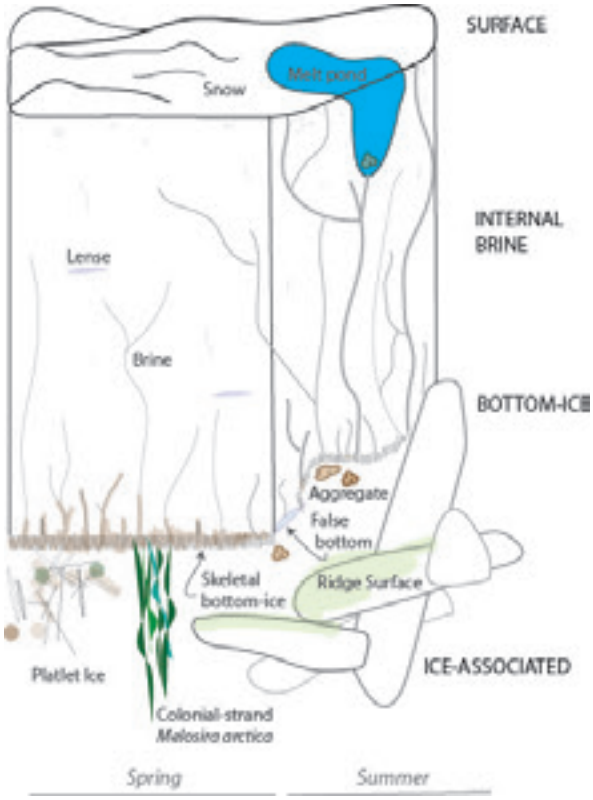
Drifting around the Arctic Ocean largely at the whim of winds may seem like a wasted opportunity when compared to the targeting of specific locations that is more typical of research voyages.

"On the contrary," says Campbell, "the slow drift gives us time to do in-depth work across time and space that is just not possible with other cruises."

The BREATHE and Micro-SHIFT drifts on RV *Kronprins Haakon* have been relatively short, on the order of weeks, with optimised sampling for a magnified view of biological processes. The insights are nonetheless revealing. For example, the team found a lot of *Pseudonitzschia* algae in the sea ice during the 2025 Micro-SHIFT drift. These algae could produce a neurotoxin that affects other life forms in the ecosystem, but the analysis done so far in the lab of Michele Fabris has shown that this may not be happening within the ice—at least not under the conditions of this drift.

ALGAE HUNTING IN THE HIGH ARCTIC

Most of the research on sea-ice algae has focused on the few centimetres of ice in contact with the ocean. This is where highly productive diatoms accumulate in spring when daylight returns to the Arctic. But during the maiden voyage of RV *Kronprins Haakon* to the North Pole in 2022, Campbell and colleague Benjamin Lange noticed something. Most of the algae were not in the bottom-ice. Instead, the algae were concentrated in the form of floating masses beneath the ice, known as aggregates, or in the deformed ice of ridges that can be metres thicker than the surrounding level ice, and have a much more complex geometry. These often-overlooked biological



The complexity of sea ice. Algae live at the surface of sea ice, inside the brine and on the underside. *Image: Karley Campbell / UiT The Arctic University of Norway*

hotspots–the Arctic's hidden gardens–might have an important role in determining the biodiversity and productivity of sea ice algae.

"Knowing the gardens were there was one thing. Sampling them was quite another," says Lange.

With some quick thinking and the use of a remotely operated underwater vehicle (ROV) to see where Lange could not, they were able to pump samples of the hidden algae to the surface. Measurements on board the vessel soon showed that, compared to the bottom-ice, these hidden gardens had unique algae species and rates of production. They were alive and seemed to be doing quite well. Being different species of algae than in the bottom-ice could mean that they are better suited for future conditions of the Arctic Ocean. This is being tested in lab experiments back at UiT, using algae collected from the cruises.

TRAINING THE NEXT GENERATION OF SEA-ICE RESEARCHERS

The impact of drift studies on RV *Kronprins Haakon* goes beyond the unique datasets that they have created.

In 2023, the SiDrift project paired with BREATHE to create a floating classroom as part of the drift study. In total, 23 early career researchers joined from over 20 countries as part of a field school. Instructors in biology, physics and oceanography from UiT The Arctic University of Norway and the Norwegian Polar Institute routinely took the classroom onto the ice, putting theory into practice. Participants received training that will help to propel sea-ice research into the future.

Scientists in training. Polona Itkin instructs students on 2023 BREATHE drift on making snow pits. *Photo: Rosalie McKay / UiT The Arctic University of Norway*

Knowing about the existence of the sea-ice gardens from the North Pole cruise has allowed targeted sampling in the drift studies that followed. Pumps, drones and ROVs are now part of the sea-ice biologist's arsenal, alongside the tried-and-true ice core barrel. With this sampling strategy and the time that drifting affords, several ridge gardens were effectively sampled in the 2023 and 2025 drift studies on RV *Kronprins Haakon*. Continuing this work to broaden our view of sea-ice algae from just the bottom-ice is an important mandate of the Micro-SHIFT project.

Benjamin Lange wears virtual reality goggles to suction ice algae aggregates viewed by the under-ice remotely operated vehicle (ROV). *Photos: Megan Lenss / Norwegian Polar Institute and Pedro De La Torre / Norwegian University of Science and Technology*

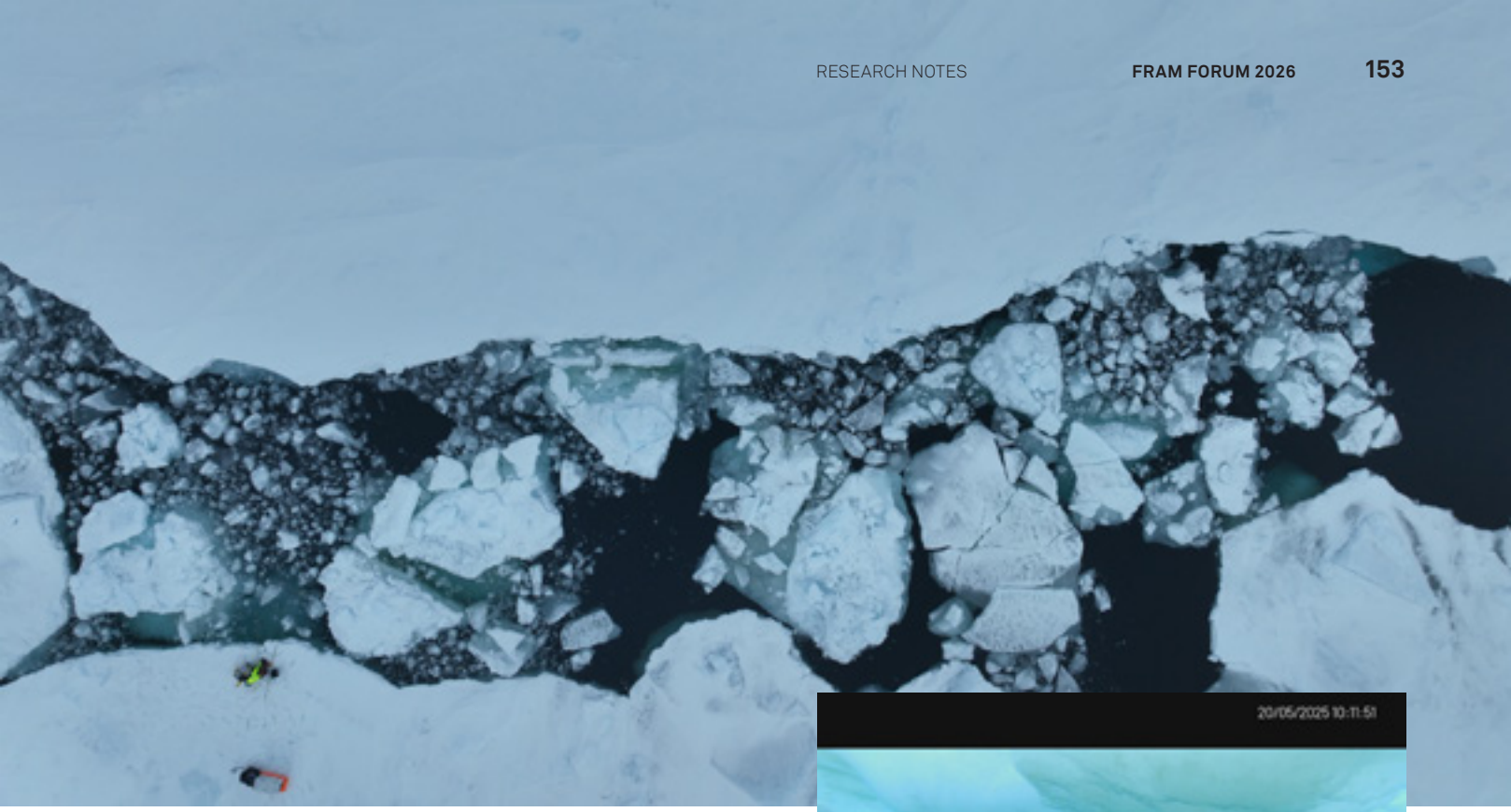
OTHER DRIFTING RESEARCH PROJECTS

The earliest research project involving drifting with the ice may be Nansen's expedition with *Fram* (1893–1896). Though the primary objective was to reach the North Pole, the expedition team collected data on water temperature, salinity, depth and currents. The ship's doctor, Henrik Blessing, recorded the presence of algae in the pack ice.

The Soviet Union established its first drifting research station on the pack ice in 1937 and maintained a series of drifting stations during the Cold War. After a hiatus, Russia resumed use of ice stations in 2003. As the Arctic Ocean's ice cover has thinned, finding suitable ice has become increasingly difficult.

More recent ship-based drift research has provided unique snapshots that help depict how sea ice, and the depths of water below it, function within the Arctic Ocean. These include:

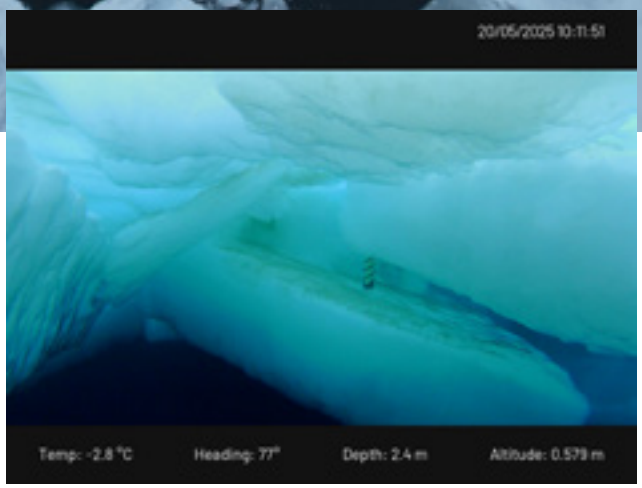
- Surface Heat Budget of the Arctic Ocean (SHEBA, 1997–1998) aboard the Canadian Coast Guard Ship *Des Groseilliers*, led by the University of Seattle, Washington
- Norwegian young sea ICE cruise 2015 (N-ICE[2015]) on RV *Lance*, led by the Norwegian Polar Institute
- Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC, 2019–2020), on the German icebreaker *Polarstern*, led by the Alfred Wegener Institute



A drift of opportunity. Drone image of scientist Karley Campbell sampling an exposed ridge surface, accessible when a lead opened during 2023 BREATHE sea ice drift. *Photo: Polona Itkin / Norwegian Polar Institute*

FROZEN LANDSCAPE—WARMING CLIMATE

Arctic sea ice is changing due to global warming. Increasingly, it is thinner and less ridged. It covers a smaller fraction of the Arctic Ocean, and for a shorter season of the year. However, sea ice remains a defining feature of the polar regions, and it will continue to be an important habitat for microorganisms in the millennia to come. It is imperative that we understand the changes that sea-ice gardens face, so that we may tend to them accordingly and ensure their integration into our ecosystem-based management of the future Arctic Ocean. ■



An ice sample being cored from a ridge garden, located and viewed here by ROV. *Photo: Emily Venables / UiT The Arctic University of Norway*

ACKNOWLEDGEMENTS

The BREATHE (325405) and SiDRIFT (287871) projects have been funded by the Research Council of Norway (RCN). Micro-SHIFT (101162830) is a European Research Council Starting Grant. Work on the 2025 sea ice drift was also supported by the RCN project DIAMOND (352217) led by Zoe Koenig.

FURTHER READING:

N-ICE special issue
https://agupubs.onlinelibrary.wiley.com/doi/toc/10.1002/(ISSN)2169-9291.NICE1

Mosaic
https://online.ucpress.edu/elementa/article/10/1/000046/119791/Overview-of-the-MOSAiC-expedition-Snow-and-sea-ice

Blog about Micro-SHIFT
https://en.uit.no/project/microshift click on Blog, rightmost in the banner mid-page

Ann Kristin Balto // Norwegian Polar Institute

Female polar aviator

RETROSPECTIVE

The actual flight over the North Pole was no big deal, as I see it. But the expedition gave me self-confidence, which I was low on.

Ingrid Pedersen interviewed in *Dagbladet* newspaper in October 1996.

A search for transpolar flights in the Norwegian Polar Institute Photo Archive turns up a few shots of a red-haired woman under the wing of a green and black Cessna 205 propeller aircraft. She's going flying!

The woman in the photo is aviator Ingrid Pedersen (née Liljegren), who in 1963 became the first woman to fly an aircraft over the North Pole. She accomplished this feat with her husband, Einar Sverre Pedersen, in a Cessna 205 named *Snow Goose*. Ingrid was instructed that if the engine cut out right after take-off, "then you have to dip the nose hard, make sure you keep your speed up, and just hope you touch down somewhere fairly level..." A red fire engine was on standby. The take-off from Fairbanks, Alaska went well, but the aircraft was heavily loaded, and fair weather was needed, as icing on the aircraft would increase the load.

Now, at last, they were airborne, en route to the North Pole. Ingrid's husband was responsible for the navigation, which was dicey when flying near the magnetic north pole, which causes compass deviation. As safety equipment, they were carrying life jackets and a life raft in case they had to make an emergency landing, and they had a backup radio, too. They flew over Fletcher's Ice Island, a drifting iceberg on which a US naval research laboratory had been established in the Arctic Ocean. When they passed the North Pole after 17 hours in the air, they radioed the following position: "*Resolute Bay, November Eight, Three Five Seven Zulu, position 90 degrees north, altitude 3,000 feet. Over.*"

Ingrid Pedersen in Ny-Ålesund, spring 1970. *Photo: Tor Killie / Norwegian Polar Institute Photo Archive*

Their flight then continued to Station Nord, Greenland, where the couple enjoyed a lavish dinner with almost the entire station crew of 35. Only one man was missing; he had been stationed there for ten years and was wary of women, Ingrid was told. After a good night's sleep, they took off for Bodø, Norway, but they encountered fog and the aircraft lost altitude due to icing. As the aircraft descended, the temperature rose, melting the ice layer so they could land safely in Bodø.

The Pedersens later settled in Svalbard, where Ingrid worked for the Lufttransport airline and flew missions for the Norwegian Polar Institute. ■

Kjetil Rydland // UiT The Arctic University of Norway

John P Smol —Archivist of the Arctic

IN BRIEF

The Mohn Prize for 2026 has been awarded to John P Smol for his pioneering research in palaeoecology and his leadership in understanding Arctic environmental change. His studies of the "memory" of Arctic lakes have provided essential tools to detect pollution, climate shifts, and biodiversity loss.

SCIENTIFIC DETECTIVE

The Mohn Prize is awarded every two years to recognise outstanding Arctic research that has had significant international impact. Professor Smol earned this distinction by acting as a scientific detective. His crime scenes are Arctic lakes, and his clues are microscopic remnants of life, preserved in layers under these waters.

Because these sediment layers accumulate over centuries, they act like pages in a history book. By "reading" these pages, Smol can reveal how ecosystems looked hundreds of thousands of years ago, providing a baseline to measure how much they have changed due to human activity.

HOW TO MEASURE NATURE'S HEALTH?

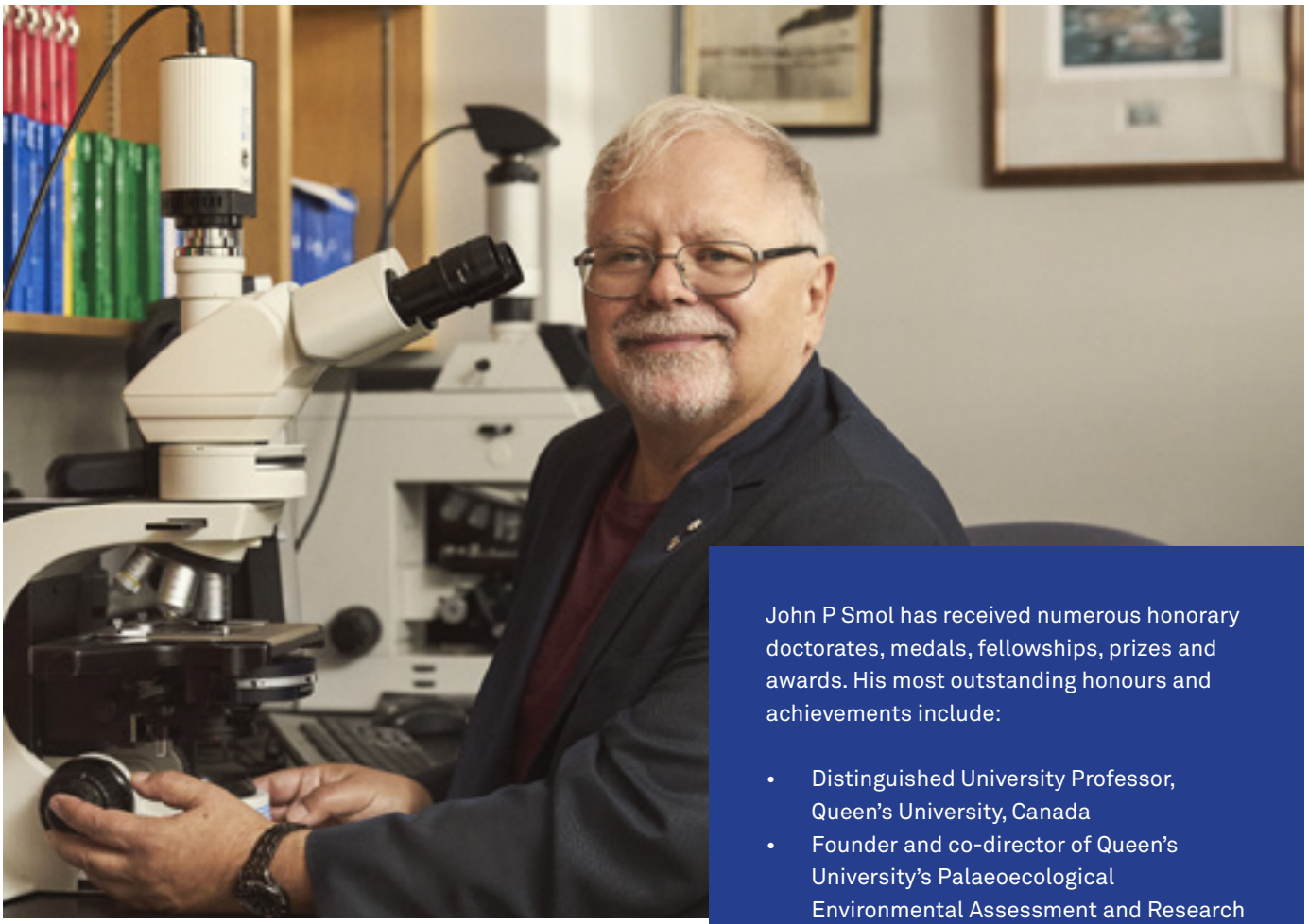
One of the primary reasons the Mohn Prize committee selected Smol is his development of indicators that measure environmental health. Smol's methods read signals to detect acid rain and industrial pollution, climate-driven shifts in biological communities and early warning signs of ecological disruption before they become irreversible.

His research is not merely academic; it has practical, "real-world" value. His findings have led to evidence-based efforts to combat pollution and have informed international discussions on sustainable development and Indigenous rights in the North.

A LEADER AND COLLABORATOR

The committee also highlighted Smol's role as a global leader and mentor. In 1991, he founded the Palaeoecological Environmental Assessment and Research Laboratory (PEARL), a world-class institution that has trained over 100 graduates to continue vital environmental research.

Smol's career is defined by an extraordinary level of productivity and influence. He has contributed to more than 700 scientific articles and over 20 books. His work has been published in top-tier journals like Science and Nature and he is a tireless public communicator, helping the general public and policymakers understand complex climate data.



Smol uses a microscope to "read" the information contained in tiny fragments of organic material retrieved from layers of sediment under Arctic lakes. *Photo: Sylvie Li*

John P Smol has received numerous honorary doctorates, medals, fellowships, prizes and awards. His most outstanding honours and achievements include:

- Distinguished University Professor, Queen's University, Canada
- Founder and co-director of Queen's University's Palaeoecological Environmental Assessment and Research Laboratory (PEARL)
- President of the Academy of Science, Royal Society of Canada (2019-2022)
- Canada Research Chair in Environmental Change (2001–2022)
- Founding editor of the Journal of Palaeolimnology
- Editor-in-chief of Environmental Reviews

John Smol somewhere in the Northwest Passage. *Photo: Joshua Theinpont*

RESEARCH MATTERS FOR THE FUTURE

The Arctic is currently facing immense pressure from global warming and human activity. The Mohn Prize committee emphasised that Smol's work is crucial because the future of Arctic freshwaters is highly uncertain. Without the tools he developed, scientists and leaders would be fumbling in the dark when trying to set goals for management, conservation and restoration.

By awarding Professor Smol this prize, the international community recognises that the small, often overlooked lakes of the Arctic are actually sensitive archives of our planet's health. His research ensures that as we move into an uncertain future, we have a clear scientific foundation to protect the water and ecosystems we depend on. ■

Espen Viklem Eidum and Martí Amargant-Arumí // UiT The Arctic University of Norway

Out of the white, and into the blue

IN BRIEF

On Tuesday 2 September 2025, the research vessel *Kronprins Haakon* reached the North Pole with an international team of researchers led by UiT The Arctic University of Norway, NORCE Norwegian Research Centre and the University of Bergen.

The expedition was organised and funded through the prestigious synergy grant i2B – Into the Blue from the European Research Council.

"Reaching the North Pole with RV *Kronprins Haakon* is a historic milestone for UiT and for the i2B Into the Blue project," says expedition leader Jochen Knies at the Department of Geosciences, UiT. "Thirty years ago, I first stood here under very different conditions. This time, we sailed through stretches of open water where once the ice was thick and unbroken. That striking change underlines why our work is so important."

According to Knies, investigating how the Arctic Ocean has reacted during previous warm periods—when the summer ice may have disappeared completely—can prove crucial for predicting the future of the Arctic.

DURING THE EXPEDITION, THE RESEARCHERS:

- retrieved high-resolution sediment cores to reconstruct temperature, sea ice, oceanography and ecosystems during previous warm periods
- compared the data with modern observations to understand the transition to an ice-free Arctic Ocean
- investigated whether the past can provide a warning of future tipping points in the climate system

Knies believes that the combination of an integrative approach, the willingness to adapt, and the commitment to strengthening the climate archive of the Arctic is what ultimately secured the renowned synergy grant. He is glad he and his team persevered through multiple rejections of what he believed to be a worthy idea.

The research team, consisting of 25 participants affiliated with UiT The Arctic University of Norway, the University of Bergen, NORCE and the Alfred Wegener Institute in Germany, gathered at the North Pole. *Photo: Tim Kalvelage*

Conditions have changed dramatically since Jochen Knies was at the North Pole for the first time. *Photo: Henry Patton / UiT The Arctic University of Norway*

Knies co-led the expedition with Stijn De Schepper from the University of Bergen and NORCE. As far as Professor Matthias Forwick, Head of the Department of Geosciences, is aware, this is the first expedition led by UiT to reach the North Pole.

"We are excited about the expedition because it will give us insight into what the Arctic Ocean looked like during previous warm periods. This will give us a better understanding of what is happening today – and what we can expect in the future. The Into the Blue project is an important contribution to Arctic Ocean 2050," says Forwick. Arctic Ocean 2050 is an ambitious 10-year project that Norway is undertaking in preparation for the upcoming International Polar Year 2032-2033. ■

FURTHER READING:

About the i2B Arctic Ocean Expedition:
https://in2blue.eu

About Arctic Ocean 2050:
https://arcticocean2050.no

Jørgen Berge and Bodil Bluhm // Arctic Ocean 2050

What will happen when the Arctic Ocean has no ice?

IN BRIEF

The Arctic Ocean is fundamentally changing. Within the next 25 years, it is likely that we, for the first time in recent history, will witness an Arctic Ocean without summer sea ice. How will that affect ecosystems, wildlife and climate, and how will society respond?

Arctic Ocean sea ice extent in September defined as regions with sea ice concentration of more than 15%, from a situation typical for the 1980s (5.5 million km^2), the past decade (3.3 million km^2), and the practically ice-free state predicted for the Arctic Ocean by 2050 (<1 million km^2). Based on data from Jahn et al (2024) Nat Rev Earth Environ 5: 164–176. Diagram: Are Olsen / University of Bergen

Representatives from some of the Arctic Ocean 2050 member institutions. Back row, left to right: Roar Skålin (Norwegian Meteorological Institute); Jostein Mårdalen (Geological Survey of Norway); Tore Furevik (Nansen Environmental and Remote Sensing Centre); Andreas Østhagen (Fridtjof Nansen Institute); Are Olsen (University of Bergen); Jørgen Berge (UiT The Arctic University of Norway); Tor Eldevik (University of Bergen). Front row, left to right: Camilla Stoltenberg (NORCE) and Camilla Brekke (Norwegian Polar Institute). *Photo: Kjetil Rydland / UiT The Arctic University of Norway*

The Arctic Ocean is the smallest of the world's oceans, yet it plays a critical role in climate, environmental, and political systems. Its waters are vital for global ocean circulation. Arctic ocean–atmosphere heat exchange influences global weather patterns. Arctic sea ice regulates Earth's temperature and the Arctic Ocean is home to diverse marine species and unique, fragile ecosystems.

Because of its strategic location, abundant natural resources, and emerging shipping routes, the Arctic Ocean is significant for security politics and global governance, in changing, intensifying and interlinked ways.

We now see climate change affect everything from the deep ocean to the atmosphere, creating cascading impacts on nature and society.

In addition, the Central Arctic Ocean is immensely remote—a deep ocean with polar nights and winter sea ice. Studying it is incredibly hard, not to mention expensive.

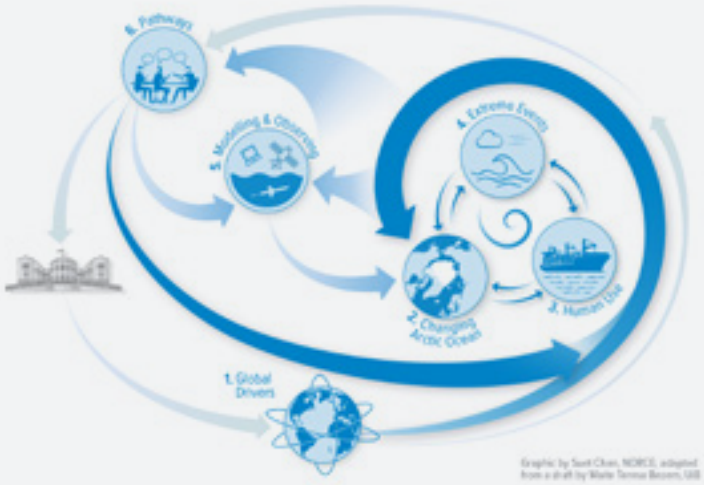
This is why a great deal of research—even basic research—remains to be done. We know too little, and now the ocean is changing, with unpredictable outcomes.

Shifts in the range of important commercial fish stocks, increased ocean heating and acidification, ecosystem changes of unknown proportions—all are in the realm of the possible, and we need to know in advance. Only then can we plan and take appropriate measures.

This is the backdrop and rationale for why the Norwegian government is now initiating

ARCTIC OCEAN 2050 IN NUMBERS

- 1 ocean
- 2 billion NOK (50% own contribution from the 18 consortium partners)
- 10 years
- 18 institutions
- Hundreds of participants
- Interdisciplinary and integrated
- Both fundamental and applied research
- Feeds into the International Polar Year and the UN Ocean Decade



Arctic Ocean 2050 will focus on six research themes. *Graphic: Suet Chan / NORCE, adapted from a draft by Maite Teresa Bezem / University of Bergen*

the largest single research programme ever to be conducted on public funding in Norway. Starting in 2026, a total of 18 Norwegian research institutions, of which ten are Fram Centre members, will join forces over a period of ten years in the Arctic Ocean 2050 research programme.

Arctic Ocean 2050 is designed to directly engage with already emerging issues that have gained new urgency due to global environmental, geopolitical, and technological shifts, addressing interactions among ocean, ice, atmosphere, ecosystems, and human activity.

The programme's six research themes span the natural and social sciences, generating extensive sample collections, data and knowledge, to support sustainable management of the Arctic Ocean.

By coordinating efforts through Arctic Ocean 2050, Norway can create a solid foundation for future management and preparedness—environmental, economic and political. The Arctic Ocean 2050 programme will be a unique interdisciplinary effort with scientific teamwork at its core. ■

FURTHER READING:

Additional information about Arctic Ocean is available at *https://arcticocean2050.no*

FRAM – High North Research Centre for Climate and the Environment (The Fram Centre)

We consist of employees from 21 institutions involved in interdisciplinary research and outreach in the fields of natural science, technology, and social sciences.

We contribute to Norway's sound management of the environment and natural resources in the north – and we aim at excellence in said management. With scientific research as our foundation, we communicate knowledge to management authorities, the business communities, and the public.

Based in Tromsø, Norway.

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- Akvaplan-niva
- CICERO Centre for International Climate Research
- Institute of Marine Research
- National Coastal Administration
- National Veterinary Institute
- NGU – The Geological Survey of Norway
- NGI – The Norwegian Geotechnical Institute
- NILU
- NINA – Norwegian Institute for Nature Research
- NIKU – Norwegian Institute for Cultural Heritage Research
- Nofima – The Norwegian Institute of Food, Fisheries and Aquaculture Research
- NORCE
- Norwegian Meteorological Institute
- Norwegian Polar Institute
- Norwegian Institute for Bioeconomy Research
- Norwegian Institute for Water Research
- Norwegian Mapping Authority
- Norwegian Radiation and Nuclear Safety Authority
- SINTEF Group
- UNIS – The University Centre in Svalbard
- UiT – The Arctic University of Norway
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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

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