Norsk
Polarinstitutt

ANNUAL REPORT

2021

Arctic

Antarctica

Norwegian Polar Institute

Scientific knowledge and advice to the Norwegian authorities about the Arctic and the Antarctic.

ANTARCTICA Every year, the Norwegian Polar Institute sends around 70 – 80 containers of supplies to Antarctica by sea. From the unloading site at the ice margin, these containers are transported inland by tractor to the Troll Research Station, which is located approximately 250 km from the coast of Dronning Maud Land.
Photo: Samuel Martinez Llobet / Norwegian Polar Institute

Arctic

Antarctica

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In many places in this annual report, the Norwegian Polar Institute is abbreviated to 'NPI'.

In the online version, links are provided to the publications referred to in the texts and the publication summary.

Director's Report

Ole Arve Misund

Ole Arve Misund
Director of the Norwegian Polar Institute

2021 PROVED TO BE YET ANOTHER YEAR DURING WHICH our activities were affected by the COVID-19 pandemic in both the Arctic and the Antarctic. We worked from home for much of the year. We kept in touch with each other by telephone, e-mail, Teams and Zoom. General meetings were held digitally, with staff taking part from Tromsø, Ny-Ålesund, Longyearbyen and Troll in Antarctica.

Despite the pandemic and the limitations that it entailed, we carried out all the assignments allocated to us by our owners at the Ministry of Climate and Environment.

During the year, we took part in five research cruises in the northeastern Barents Sea and the Arctic Ocean using the research vessel Kronprins Haakon, as part of the Nansen Legacy research programme. We led a separate research cruise to the Fram Strait, partly to maintain times series dating back over forty years in the marine area between Svalbard and Greenland.

In Svalbard, most fieldwork was carried out as planned, in close cooperation with staff at Ny-Ålesund Research Station and the office in Longyearbyen.

Our role as host for the Ny-Ålesund Research Station continued in close cooperation with Kings Bay AS, and the level of activity amongst foreign actors at the site picked up significantly after the pandemic had put an end to travel and limited the scope of work last year.
In June, Minister of Climate and Environment Sveinung Rotevatn opened the upgraded service building in Ny-Ålesund. Among other things, the Minister was briefed on the increase in greenhouse gases in the atmosphere when he visited the Zeppelin Observatory.

Later in the summer, during Arendal Week, the Minister again met the "polar recruits" when they collected plastic waste to draw attention to the issue of marine litter.

In Antarctica, we used the vessel Malik Arctica to establish a new study field in the Southern Ocean, in connection with the transporting of supplies to the

"Our scientific production was once again solid in 2021."

Troll Research Station. On board were scientists who took various oceanic measurements in what is considered to be one of the world's least studied oceans. Logistics in Antarctica became particularly challenging in 2021. During the autumn, the glacier at our permanent "harbour" calved along the ice margin of Dronning Maud Land, which had been used for over 20 years as an unloading point for supplies to Troll. Assistance was needed from the icebreaker Kronprins Haakon and its helicopter. This controversial, but unavoidable, measure was ordered by the Ministry of Climate and the Environment. The remaining research cruises in the North were carried out using the Institute of Marine Research (HI) research vessel G. O. Sars and the Governor of Svalbard's vessel Polarsyssel, and we are very grateful to these institutions for making these vessels available.

In January, the Norwegian Directorate of Public Construction and Property (Statsbygg) began the task of upgrading and modernising Troll Research Station. This work continued throughout the year, and the Institute has participated in the project work. It is also worth noting that the installation of a new emergency power supply system for Troll was completed in 2021.

Our scientific production was once again solid in 2021. The Norwegian Polar Institute ended the year with the highest scientific production in the Research Council of Norway's network arena, with 2.0 publication points per researcher among the Group II institutes, which have a societal mission which leads to direct funding from the ministries.

We were involved in many applications for research funding, and were awarded funding for many projects financed by the Research Council of Norway, the EU and other sources. We successfully fulfilled our remit to provide environmental advice and, at the end of the year, we received important news when the Research Council of Norway awarded funding of at least NOK 150 million for the

TONe (Troll Observing Network) project being carried out by the Norwegian Polar Institute and partners to develop an observation system around the Troll Research Station. More good news was to follow when the Svalbard Integrated Arctic Earth Observing System (SIOS), of which the Norwegian Polar Institute is a partner, received funding for a further five years.

At the year-end 2020/21, a settlement was reached between the Institute of Marine Research (HI) and the Italian shipbuilding group Fincantieri, which will enable the construction project for the research vessel Kronprins Haakon to be concluded. In August, we took over formal ownership of the vessel, while continuing the cooperation where HI operates the ship and UiT - The Arctic University of Norway, HI and the Norwegian Polar Institute are the largest users.

During the year, a new management model was developed for further professional cooperation at the Fram Centre, where the Norwegian Polar Institute is an important actor. As part of this, five major collaborative projects will commence in 2022, with the Norwegian Polar Institute being heavily involved in a number of these.

Outreach work is important in order to explain what we do, and in 2021, we continued to develop websites, exhibitions, social media and other works in order to reach out with polar knowledge to the general population. It is worth noting that one of our communicators, Elin Vinje Jensen, received forskning.no's award for the best article of the year about the polar explorer Brit Hofseth (this article can be read on page 26).

I would like to thank the employees of the Norwegian Polar Institute for their hard work, dutiful compliance with infection control measures, little travel, and last but not least, the challenging follow-up of the quarantine regulations. Many of the tasks that have been performed would not have been possible without either the excellent cooperation with numerous actors both in Norway and abroad or the strong commitment from employees from every department at the Norwegian Polar Institute.

Who are the Norwegian Polar Institute?

The Norwegian Polar Institute is a directorate under the Ministry of Climate and Environment which carries out scientific research and environmental monitoring in the Arctic and Antarctica.

The Norwegian Polar Institute provides the Norwegian state with expert and strategic advice concerning polar issues, represents Norway internationally in various contexts, and functions as Norway's environmental authority in the Antarctic. Climate, pollutants, biodiversity and geological and topographic mapping are key tasks for the Institute. The same can be said of environmental monitoring in the polar regions, bilateral cooperation with Russia and circumpolar cooperation in the Arctic and Antarctica.

Fieldwork and data collection are a vital part of the operation through, for example, studies of polar bears in and around Svalbard, drilling of ice cores in the Arctic and Antarctic, and measurement of sea ice in the Arctic Ocean. The Institute also equips and organises major expeditions. The Ministry defines the scope and remit of the Institute, in consultation with the other environmental protection authorities. In addition, the Institute undertakes tasks financed by other ministries, environmental authorities and research institutes, the Research Council of Norway, the European Union and others.

The Institute represents Norway in numerous international collaborative forums and collaborates with research institutes around the world. The results of research and monitoring projects are submitted to Norway's central administration, research partners, international

management processes, expert groups, schools and the general public. The Institute produces and publishes exhibitions, books, reports and the scientific journal Polar Research.

The Norwegian Polar Institute's predecessor - Norges Svalbard- og Ishavs-undersøkelser (Norway's Svalbard and Arctic Ocean Research Survey, NSIU) - was founded in 1928, but its roots dated back to the Norwegian State-sponsored Spitsbergen expeditions, which had been receiving State funding since 1909. The Institute is based at the Fram Centre in Tromsø, together with around 20 other scientific institutions with a knowledge of the northern and polar regions. In addition, the Institute has staff at offices in Ny-Ålesund and Longyearbyen in Svalbard, and at the Troll Research Station in Dronning Maud Land in the Antarctic. At the end of 2021, the Institute had 196 employees from 24 nations.

Norway's initiatives relating to climate and the environment have been divided into 24 environmental goals, with six specific performance areas. The Institute aims to contribute to attainment of the goals within the following performance areas:

- Biodiversity

- Pollution

- Climate

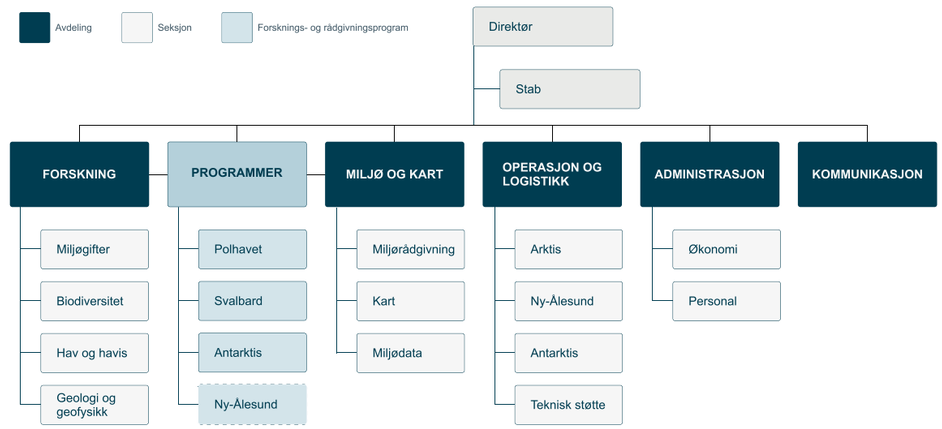
- The polar regions

For more information about the various performance areas, see the website npolar.no

POLAR PIONEER Botanist Hanna Resvoll-Dieset (later Resvoll-Holmsen) was the first female Norwegian research scientist in Svalbard. The work that she and her colleagues carried out in Svalbard in the early 20th Century laid the foundations for the formation of Norges Svalbard- og Ishavs-undersøkelser (Norway's Svalbard and Arctic Ocean Research Survey, NSIU) in 1928, which subsequently became the Norwegian Polar Institute in 1948.

Photo: Gunnar Holmsen / Norwegian Polar Institute

In 2021, the management consisted of Director Ole Arve Misund, Head of Administration/Deputy Director Geir Andersen, Heads of Research Nalân Koç and Harald Steen (from September 2021), Head of Environmental Management and Mapping Evy Jørgensen, Head of Operations and Logistics John E. Guldahl, and Communications Director Anja Salo. In addition, International Director Kim Holmén was also part of the management team until July 2021.



Departments, sections and programmes, Norwegian Polar Institute.

UNDER THE MAGNIFYING GLASS Every summer, researchers from Norway and elsewhere come to Kongsfjorden near Ny-Ålesund to study the natural environment. The photo shows a male eider duck strutting around on one of the small islands in the fjord. *Photo: Geir Wing Gabrielsen / Norwegian Polar Institute*

The UN Sustainable Development Goals (SDGs)

As a State-owned enterprise, the Norwegian Polar Institute has a responsibility to contribute to the national effort relating to attainment of the UN Sustainable Development Goals. We have identified the following SDGs as being of greatest relevance for our work:

- SDG 9 Industry, innovation and infrastructure
- SDG 12 Responsible consumption and production
- SDG 13 Climate action
- SDG 14 Life below water
- SDG 15 Life on land

For example, the Norwegian Polar Institute operates Environmental Monitoring Svalbard and Jan Mayen (MOSJ), which is a key part of the national environmental monitoring system and contributes to SDGs 14 and 15. The Institute's strengthening of the knowledge base in the northern marine areas, combined with its contribution to the academic basis for Norway's management plans, constitutes important knowledge with regard to SDGs 9, 13 and 14.

In the performance of the Institute's internal activities, work is being carried out which can contribute to attainment of the SDGs. For example, an environmental impact assessment is being carried out for all of the Institute's activities in Antarctica, and measures have been implemented to reduce the environmental impact and ensure that no environmental damage occurs.

As regards operation of the Troll Research Station, a comprehensive environmental assessment has been prepared for use as a basis for the activities. In 2021, the Institute contributed to the future development of Troll, with energy-efficient operation as a key element. Green operation at Troll can contribute to the attainment of SDGs 9, 12 and 13. In 2021, the Norwegian Polar Institute entered into an agreement concerning a new supply vessel for Antarctica. During the procurement process, emphasis was placed on assessing any environmental consequences, as the vessel which was chosen is relatively small, consumes less fuel and causes less pollution than previous supply ships.

The COVID-19 pandemic meant that the Institute's employees made fewer trips in 2021. As a result, the Institute has become more aware of, and familiar with, the use of digital meeting platforms. We expect this to also reduce the amount of travel in the future, thus reducing the organisation's contribution to CO_2 emissions (SDG 13).

The role of host in Ny-Ålesund

Report to the Storting No. 32 (2015-2016) "Svalbard" stresses the importance of ensuring that Norway acts as a clear host in Svalbard. This is set against the backdrop of the increasing interest in the Arctic and the fact that institutions from more and more countries are conducting research in Svalbard.
The Norwegian Polar Institute performs the role of official Norwegian host in Ny-Ålesund, which means that the Institute is the point of contact for research and all associated activities, and for the planning and organisation of visits from officials and the media. The Institute operates Sverdrup Station and the Zeppelin Observatory as part of the Ny-Ålesund Research Station.

Research collaboration at the Fram Centre

FRAM - High North Research Centre for Climate and the Environment (the Fram Centre) comprises around 20 institutions, including the Norwegian Polar Institute, with joint tasks within the natural sciences, social sciences and technology. The tasks consist of multidisciplinary research, advice, management and dissemination in the High North. During 2022, five major research fields will be initiated in which the member institutions will cooperate:

How northern ecosystems are being affected
led by UiT The Arctic University of Norway

From mountain to fjord
led by NINA – Norwegian Institute for Nature Research

Areas under pressure
led by the Institute of Marine Research

Sustainable management of the Arctic Ocean
led by the Norwegian Polar Institute

Tana River,
led by NINA – Norwegian Institute for Nature Research.

Key figures

Key figure	2021	2020	2019
Number of employees	219	213	187
Number of full-time equivalents worked	184	172	167
Number of contracted full-time equivalents	192	181	177
Allocation of operating expenses, item 01-50; see letter of allocation	357,960,000	356,701,000	323,915,000
Operating expenses recognised in the accounts: item 01-50	381,141,685	381,606,385	322,487,660
Degree of utilisation item 01-50, specified as a percentage	106	107	100
Wage share of operating expenses	159,260,780	145,101,606	140,215,590
Wage costs per full-time equivalent worked	865,548	843,614	839,614
Wage share as a percentage	42%	38%	43%
Total revenue, item 01-50; see letter of allocation	86,731,000	84,651,000	87,272,000
Revenues recognised in the accounts; item 01-99	126,688,125	111,629,684	100,159,795

Photo: Geir Gotaas / Norwegian Polar Institute

Articles

On the following pages, we present a selection of articles on the polar regions dating from 2021

KEY AREA The Norwegian Troll Research Station in Antarctica is located at Jutulsessen, 235 kilometres from the coast. *Photo: Harald Fast Aas / Norwegian Polar Institute*

Elin Vinje Jenssen ——— *Norwegian Polar Institute*

Green light for new research infrastructure in Antarctica

A new observation system around Troll could see the light of day in the next few years.

RESEARCH An ice core is extracted from the sea ice in the Southern Ocean, Dronning Maud Land. These ice cores provide information about biochemical processes in the ocean. A southern giant petrel and Adélie penguins look on. *Photo: Samuel Martínez Llobet / Norwegian Polar Institute*

ONE OF THE PROJECTS TO RECEIVE FUNDING is the Troll Observing Network (TONe), which includes equipment for atmospheric, cryospheric, marine and Earth observations from the areas around the Norwegian Troll Research Station in Antarctica.

A number of Norwegian and foreign institutions are involved in TONe, which is being led and coordinated by the Norwegian Polar Institute.

"The infrastructure will strengthen Norway's position in Antarctic research and give Norwegian and international researchers access to observations which will be of great importance in climate and soil system research, and have the potential to form the basis for world-leading research," wrote the Research Council of Norway on its website when the news was announced before Christmas 2021.

"Antarctica is the most desolate and inaccessible continent on the planet. Nevertheless, it is here that the key to some of our greatest societal challenges lies hidden. The Research Council of Norway's contribution to long-term monitoring programmes will be of enormous value as regards the global climate, and Norway's further work on the continent," says Ole Arve Misund,Director of the Norwegian Polar Institute.

Harsh and demanding

The innovations will complement the existing infrastructure at and around Troll Research Station and contribute to a more complete and modern research facility.

"There is an enormous international need for the development of observation systems in Antarctica, but establishing and operating fixed long measurement series in Antarctica is challenging. TONe will be an invaluable contribution in this context," says Birgit Njåstad, Head of the Antarctic Programme at the Norwegian Polar Institute.

A number of stations on the Antarctic continent have comprehensive observation programmes, but the size, extreme weather conditions and natural features of the continent limit the geographical coverage of observations. Greater data density will be vital if we are to understand the overall role that Antarctica plays in global systems. TORe will contribute by plugging an observation gap in the area of Dronning Maud Land on land, in the air and in the surrounding marine areas.

Natural environment under pressure

Birgit Njåstad stresses that efforts to increase the amount of observational data obtained from Dronning Maud Land are needed, in light of the ongoing climate change that is increasingly impacting on the planet's southernmost continent.

"The Antarctic plays a key role with regard to many societal challenges, and we need to ensure data collection and access over time from across the continent, in order to monitor developments and changes," says Njåstad.

However, the challenges are mounting up. Around 90 percent of all ice on Earth occurs in the Antarctic. In recent decades, significant warming has been recorded across some parts of Antarctica. The consequences of this climate change are manifold. Sea ice is expected to shrink and melting glaciers from the huge ice masses in the Antarctic will contribute greatly to global sea level rise. These changes are affecting people around the globe, initially those living in low-lying areas which are at greatest risk of being flooded by ocean water. However, habitats for plants and animals will also change (source: UN climate report)

Troll – a portal to Antarctica

Troll is considered to be a key area for obtaining research and monitoring data on the natural environment in Dronning Maud Land. The station is located in the inland mountainous area of Jutulsessen, 235 km from the coast. There is an airstrip on the blue ice nearby, which acts as a portal for travellers to and from Antarctica and within the continent.

"Through TONe, we have worked with a number of other Norwegian partners to put forward a proposal for research infrastructure which will deliver long time series in all spheres for many years to come. It is wonderful to see that this initiative has now received support. The utilisation of Troll will be strengthened," says Project Manager Christina A. Pedersen from the Norwegian Polar Institute.

TONe will also include shared research services, such as a drone service, mobile laboratory facilities, access to the Troll Supply Vessel observation platform and access to field instruments for research campaigns. The network will also provide the national and international scientific community with access to all TONe data.

The partners in TONe are, in addition to the Norwegian Polar Institute, the University of Oslo, the University of Bergen, the Norwegian Institute for Air Research (NILU), NORSAR and NORCE, as well as the British Antarctic Survey (BAS), the University of Leeds and the University of Washington.

PLASTIC CRUISE In the summer of 2021, researchers and other crew members set off on a plastic cruise to Svalbard on the research vessel Kronprins Haakon. *Photo: Trine Lise Sviggum Helgerud / Norwegian Polar Institute*

Trine Lise Sviggum Helgerud —— *Norwegian Polar Institute*

Developing microplastic monitoring in the Arctic

Microplastic samples from the air, ice, water and seabed will be analysed after the Norwegian Polar Institute's first “plastic cruise”.

THE ARCTIC IS MORE VULNERABLE TO PLASTIC POLLUTION THAN ANYWHERE ELSE in the world. This is because the food chains in the Arctic are short, which means that any plastic entering the bottom of the food chain will accumulate faster than in other ecosystems.

"Plastic pollution is both a relatively new problem and a global issue. The world's oceans are being filled with plastic. We must find out where the microplastics in the Arctic are and what can we do about the problem," says senior researcher Katrine Husum, who led the cruise.

Common standards are needed

In late June 2021, the Norwegian Polar Institute conducted its first plastic cruise. The cruise started south of Nordaustlandet, from sea ice to open sea around the southern tip of Spitsbergen and on up to Longyearbyen.

This is the first time that the Norwegian Polar Institute has embarked on what was solely a plastic cruise, which Husum believes is absolutely necessary.

"There are a few fragmented studies of microplastics in the environment here and there, but the various research studies have used different methods. If we are unable to agree on a common *standard for measuring microplastics, it will be very difficult to compare the figures and obtain credible results," says Husum.*

"I hope that we will come out of this with better methods for monitoring microplastics in the Arctic, and that we will know more about where to find this type of plastic and where we should place measuring and monitoring points in the future.

A problem without borders

The cruise is a pilot for the research and monitoring of the quantities of microplastics to be found in the Arctic environment. The experiences and studies from the plastic cruise may help to identify the direction that Russo-Norwegian cooperation should take in the future.

No single country can tackle the problem of plastic pollution alone. We must work together to find comparable methods which work across a number

LAB WORK The cruise participants collected samples from the air, ice, water, fish, plankton and seabed. Here are some of the researchers working in one of the laboratories onboard Kronprins Haakon. *Photo: Trine Lise Sviggum Helgerud / Norwegian Polar Institute*

MARINE SPECIMENS The ctenophora *Mertensia ovum and Beroe cucumis,* as well as the *sea butterfly Clione limacina. Photo: Trine Lise Sviggum Helgerud / Norwegian Polar Institute*

of countries. Norway and Russia have both an equal interest and a mutual responsibility to preserve the clean environment of the Barents Sea. We are working together under the Norwegian-Russian Environmental Protection Commission, and the work is organised into marine environment programmes, with HAV 5 concerning plastic.

The combined knowledge that Norway and Russia possess concerning the issue of plastic debris in the Barents Sea today has been compiled in a report which was published in 2022. This report is intended for managers, researchers and all interested parties. The report includes an overview of current knowledge, knowledge gaps that are apparent and lists of areas where research is needed.

1,200 samples from top to bottom

In order to understand how microplastics are transported and transferred from air to ice, ice to water and water to the seabed, we need to research the whole environment, not just parts of it," says Husum.

The strength of this cruise is that it is multidisciplinary and looks at the environment as a whole. The team includes geologists, biologists, pollutant researchers, chemists, research divers and various types of engineers who can take samples and investigate methods from air to seabed, all together, all at once.

The 17 cruise participants, together with the crew of the research vessel Kronprins Haakon, have collected samples from the air, ice, water, fish, plankton and the seabed. The result is 1,200 microplastic samples from 14 different stations.

Tom Arne Rydningen, Associate Professor at UiT's Department of Geosciences, is also part of the sediment group which is collecting samples of the unconsolidated sediments on the seabed.

"We measure the content of microplastics in the sample in the upper layers of the sediments and compare the results with deeper sediments which date from the time before humans started producing plastic," explains Rydningen.

Air samples for the first time

Air is a piece in the jigsaw puzzle of microplastic research which has attracted little research. On the cruise, senior research scientist Dorte Herzke from the Norwegian Institute for Air Research (NILU) is collecting samples of microplastics from the air. This is the first time this has been done and Herzke is very excited about the groundbreaking research.

"We don't know how the air contributes to microplastic pollution. Air can transport microplastics from contaminated places to clean places, such as the Arctic, and do it much faster than water too. We also don't know how much air contributes to microplastics in the ocean. All microplastics that can be transported and remain suspended in the air will of course descend eventually, in the form of either rain or snow."

"I expect to find quite a lot of fibres from clothing. They're small enough to be transported in the air. We might also find tiny particles of rubber which have been released from car tyres in major cities. If they're small enough, they can be transported great distances in the air.

Quality assurance using blank samples

The cruise participants wear plastic gloves as they work and their work suits contain plastic fibres.

"We can't see them, but there are microplastic particles everywhere and we cannot avoid adding plastic to the samples we collect," says Louise Kiel Jensen, Senior Adviser at the Norwegian Polar Institute.

"We can't return home and say that we have found lots of microplastics floating around in the Barents Sea if we are the source of it. We therefore also have to take blanksamples, i.e. samples from ourselves, the research vessel and the environment around the samples.

Blank samples are collected as follows:

At the moment the sample container is opened ready for filling with sediment, water, plankton or other substance that is to be sampled, the researchers also open an identical container which is left open for the same length of time and in the same place as the main sample. This makes the blank sample a sample of the environment around the sampling process.

"The findings from the blank sample are deducted from the main sample. This is how we calculate the extent to which we contaminated the sample when we took the sample out of its natural environment," says Kiel Jensen.

Elin Vinje Jenssen ——— *Norwegian Polar Institute*

Answers to sea ice riddles hidden by mud several thousand years old

Seasonal sea ice has been common in the Arctic for thousands of years, through to the present day. However, there are still some major differences between then and now.

SEDIMENT CORE The greyish-brown mud from the seabed contains remnants of ancient algae and plankton, which can tell us about the evolution of sea ice far back in time. *Photo: Katrine Husum / Norwegian Polar Institute*

OUR RESULTS STRENGTHEN THE conclusions of climate reports that anthropogenic warming is impacting on the melting of sea ice in the Arctic," says Katrine Husum, a marine scientist at the Norwegian Polar Institute.

In the autumn of 2021, Husum et al. published an article in Nature Communications Earth & Environment on the development of sea ice in the Arctic Ocean, under the auspices of the national programme The Nansen Legacy in collaboration with the Fram Centre.

The article was based on investigations carried out northeast of Svalbard during the period 2015-2018, including the first studies to be based on analyses of marine sediment samples from this part of the Barents Sea.

The sea ice is shrinking

Since 1979, when sea ice measurements first started to be taken in the Arctic Ocean, the summer ice has been reduced by as much as two-thirds. The trend is now for far more of the sea ice in the Arctic to melt every summer than is replenished during the winter. This imbalance is causing the sea ice to shrink.

Future forecasts do not make for comfortable reading either; scientists estimate that the summer sea ice in the Arctic could disappear altogether by 2030. The winter ice, which normally grows in both extent and thickness as the autumn and colder days approach, is also not growing in the same way as before.

The cause of this melting is global warming, which is occurring three times as fast in the Arctic compared with elsewhere in the world, as has been widely documented through research and reported in the UN's climate reports.

These changes are creating new conditions for life, including both wildlife and humans, and are occurring so rapidly that many animals, such as ice algae, ivory gulls and polar bears, are simply unable to adapt.

Back to the last ice age

But what did the sea ice in the Arctic look like thousands of years ago? And can today's climate scientists benefit from our knowledge of ice conditions in the past?

Together with research colleagues from a number of Norwegian institutions, Katrine Husum has examined marine sediment cores, extracted from the seabed in the northern Barents Sea, which can take us thousands of years back in time.

In this grey-brown mud are remnants of tiny algae and plankton which enable scientists to reconstruct the distribution of ancient sea ice.

The researchers found clear evidence of seasonal sea ice, dating all the way back to the last ice age.

"Our analyses show that seasonal sea ice has been continually present northeast of Svalbard since the last ice age," says Husum.

HABITATS MELTING AWAY Sea ice in the Arctic is melting so rapidly that many animals are simply unable to adapt to the changes, such as polar bears. *Photo: Adam Steer / Norwegian Polar Institute*

The sea ice was able to grow, melt and grow again – undisturbed

The last ice age began in northwestern Europe around 100,000 years ago and lasted until around 12,000 years ago, when we entered the interglacial period that we are living in now.

However, although seasonal sea ice has been continuously present since the distant past, the researchers believe there are major discrepancies between the conditions under which the sea ice existed then, compared with recent decades.

During the last ice age, thousands of years ago, there were no man-made factors to trigger the melting of the sea ice. The industrial revolution and the greenhouse gases (CO_2) which came with it belong to the modern era in which we now live.

In the past, sea ice was able to develop in a natural rhythm. It melted during the summer and expanded again during the winter, without running at a deficit.

Sea ice still exists in a natural cycle of melting and expansion, but it is now under external pressure due to global warming, which sea ice was previously spared.

"Today's sea ice situation is similar to the ice conditions which existed immediately after the last ice age, but the difference now is that the development of sea ice cannot be explained solely by natural driving forces from the atmosphere or the ocean," says Husum.

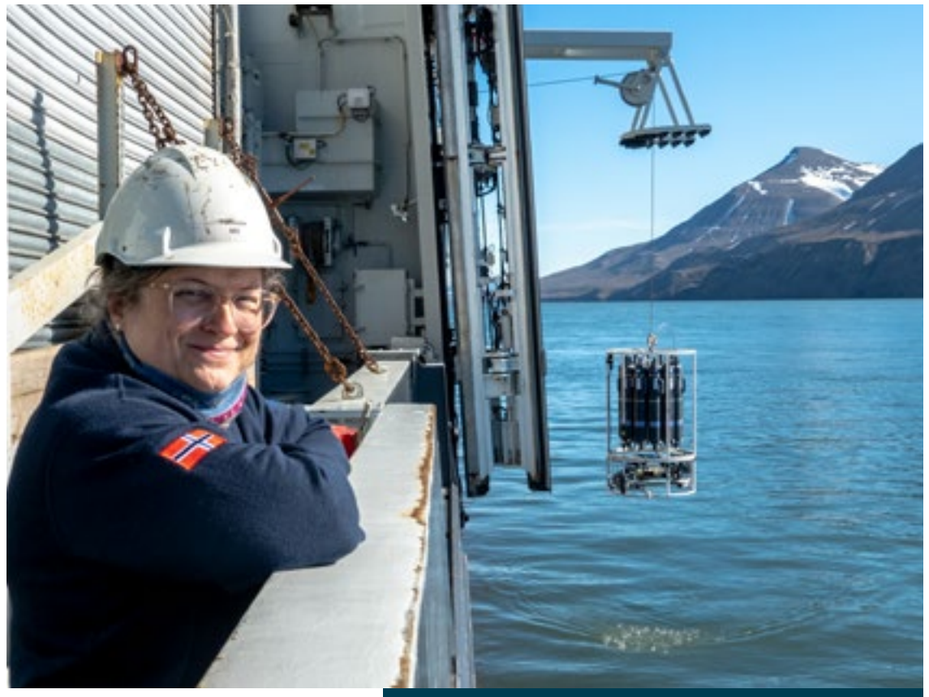
Supports the conclusions of climate reports

The warming of the planet is having a reinforcing effect on the melting of sea ice; when the ice melts, the ocean becomes darker, which in turn reduces the amount of thermal radiation reflected back into the atmosphere, causing the ocean to become even warmer. The Arctic sea ice is being put under severe pressure from several sources.

Why is what we know about the past so important for today's climate scientists?

"In order to understand the current sea ice situation, we need to know what the climate of the past was like. This enables us to compare findings over time, which can then help us to improve our understanding of processes which impact on the sea ice," replies Husum.

The surveys were carried out northeast of Svalbard during the period 2015-2018 and collectively represent the first study to be based on analyses of marine sediment samples from this part of the Barents Sea.



NOT JUST NATURAL CHANGES
"Today's sea ice is similar to the ice conditions that existed immediately after the last ice age, but the difference now is that development of the ice cannot be explained solely by natural driving forces from the atmosphere or ocean, says marine scientist Katrine Husum. *Photo: Trine Lise Sviggum Helgerud / Norwegian Polar Institute*

Reference

Pieńkowski, Anna J., et al: "Seasonal sea ice persisted through the Holocene Thermal Maximum at 80°N", *Communications Earth & Environment*, 2021

The Nansen Legacy

- Arctic research project seeking to learn more about a rapidly changing ocean climate and ecosystem.
- More than 200 researchers in physical, chemical and biological oceanography from ten Norwegian research institutions are participating, including the Norwegian Polar Institute.
- The project will last for six years (2018–2023) and is being funded by the Research Council of Norway and the Ministry of Education and Research, in addition to the institutions' own contribution.

UNTRADITIONAL The expedition to Northeast Greenland in 1939 was unique in many ways, not least because women took part for the very first time. Brit Hofseth (left) and Ebbe Arneberg are shown here. *Photo: Paul Roer*

Elin Vinje Jenssen ——— *Norwegian Polar Institute*

The talented research scientist reduced to a femme fatale

Geologist Brit Hofseth died aged 24 during a research expedition. "*She could have become a pioneer in Norwegian polar research*," says literary researcher Anka Ryall.

In Tromsø Cemetery is a small gravestone with a bronze plaque engraved with the inscription: "Geologist Brit Hofseth 24 years old". The grave is untended.

Who was Brit Hofseth?

"She was a young, ambitious geology student and the first female research scientist to take part in a Norwegian expedition to Northeast Greenland," says Professor of Literature Anka Ryall at UiT The Arctic University of Norway.

The only woman

Given that Brit was so young when she died, she left little written material behind, although there are some photographs, including some from the Greenland voyage, continues Ryall, who is currently writing a book about female polar explorers. A chapter in the book is devoted to Brit Hofseth.

"If Brit had not died prematurely at the age of 24, she could have become a pioneer in Norwegian polar research. As a geology student at the University of Oslo, she was the only woman in her year. She broke with the normative femininity of the time and was clearly independent, ambitious, headstrong and adventurous," adds Ryall.

However, despite her short life, Brit probably became the first female Norwegian research scientist to be the main character in a novel.

From Finnmark to the capital

Brit was born in Finnmark in 1917, but moved as a child to Kristiania (as Oslo was known at the time) with her mother and sister. When she was young, she started studying geology at the university, and as a graduate student she was able to take part in a research expedition to Greenland on the ship

BRIT HOFSETH *"When women finally visited the Arctic and the Antarctic, they were so unusual that they became the subject of the judgemental and critical gaze of others,"* says Anka Ryall. *Photo: Oscar Bang*

Polarbjørn in 1939. The expedition was organised by the Norwegian Svalbard and Arctic Ocean Research Survey (NSIU), the predecessor of the Norwegian Polar Institute. Brit's goal was to carry out geological surveys on Clavering Island.

The expeditionwas led by John Giæver and included a group of research scientists from Norway and Sweden, in addition to the captain and several trappers, including Henry Rudi (the famous Norwegian huntsman and polar bear hunter), three women who accompanied their husbands on board, and journalist Nils Johan Rud. The latter later wrote a romantic novel based on the trip: *Drivende grenser (Drifting boundaries)*. Many of those on the Polarbjørn voyage can be recognised in the book, including Brit Hofseth herself.

Portrayed as a temptress

In the book, Brit is referred to as the botanist Norunn, but in the novel she is more interested in seducing male expedition participants than conducting research. Little attention is given to the research, botany in Norunn's case.

The author transforms Brit into a "femme fatale", who seduces or attempts to seduce each of her male travel companions in turn. He also offers a series of intimate and sexualised descriptions of Brit together with her chosen one.

"When Rud lets Norunn die with one of her lovers at the end of the book, it symbolically underlines the view that women should not have even been on an Arctic expedition. That's why I think the novel can be used as a key to understanding some of the prevailing attitudes with regard to women in polar research until relatively recently, " says Ryall.

READY FOR AN EXPEDITION Brit Hofseth on the bridge of the Polarbjørn with Swedish glaciologist Hans W. Ahlmann (left), along with an unknown expedition participant and Nils Johan Rud, the latter being the author of the novel *Drivende grenser*. *Photo: Ebbe Arneberg / Norwegian Polar Institute*

"None of the memorial articles question Brit's abilities as a scientist"

A sudden death

Brit died suddenly and unexpectedly on 17 April 1941, during a research expedition in Troms for the Geological Survey of Norway. It is said that she collapsed while standing on deck, and that in the days leading up to her death, she had appeared happy and showed no signs of being in pain. The precise cause of her death remains unknown, but she may have been suffering from a medical condition which she was unaware of and eventually caused her death.

The novel *Drivende grenser* was published in the autumn after Brit's death. However, the image of the young student that is created in the book is disputed by some of Bris's supporters, who unsuccessfully tried to stop the book.

Colleagues pay tribute to Brit

But who was the real Brit Hofseth, before her character became distorted in a novel?

She featured in a series of obituaries and memorials. Many of these were collated in a memoir published in the spring of 1942, a few months after Rud's novel.

"In the memoir, she is praised by her male colleagues, among them the well-known Swedish glaciologist Hans Wilhelmsson Ahlmann, who took part in the expedition to Greenland. Brit is presented as a female pioneer in geology, a talented young scientist, a dear friend, even as a role model " says Ryall.

"It is likely that the memoir was intended to restore her good name and reputation after what some people probably thought was Rud's wicked character assassination, because without exception they stressed the enthusiasm she had for her work and her field, along with her friendship and companionship.

None of the memorial articles question Brit's abilities as a scientist.

Sexuality and drama

The NSIU expedition to Northeast Greenland in 1939 was special in a number of ways, not least because it was the very first time women were involved.

Brit is described by a number of people as being both beautiful and full of life.
Rud was an established writer when he wrote *Drivende grenser*, and it is easy to imagine that spicing up the polar novel with a little sexuality and drama was a good way of increasing interest in the book.

Challenging the norm of femininity?

But what led the author to portray Brit, and not the male expedition participants, as a temptress rather than as a serious scientist?

"I have often wondered whether, at a time when the norm for bourgeois femininity was a controlled, inhibited and self-protective body language, the combination of beauty and physical energy could have been one of the reasons why Rud was inspired to turn her into a femme fatale," Ryall replies.

But the outcome was one-sided. The book did not sell particularly well, but Ryall believes that those who read it may have believed the narrative.

"The novel may have influenced the image that many people still have of Brit Hofseth, and that is unfortunate, because it does not give her the legacy she deserves, as a young female and ambitious researcher in a male-dominated environment.

Young and in search of love

On the return voyage from Greenland, "something" is said to have happened between Brit and a young student on board. This is apparent from a letter which Anka Ryall has read. Novelist Rud must have been a witness, because the romance is freely recounted in *Drivende grenser*.

ON GREENLAND Brith Hofseth in the centre with trappers Henry Rudi (left) and Schjølberg Nilsen after arriving on Greenland, shown here outside a trapper's cabin at Revet. *Photo: Norwegian Polar Institute*

"Of course, this could have been just as fictional as the other sexual relationships that are portrayed in the novel, but the correspondence suggests that it may actually have happened in real life.

But, so what if it did? Brit was 22 years old, and it's probably only to be expected that a young person like her would flirt with potential partners?

"It's only natural for young people to go looking for love; sometimes they succeed, sometimes not. But Brit appears to be being observed and afforded intentions which she probably did not always have. And if she starts a relationship with the student, it will simply be assumed that he was just one of many she seduced along the way.

The polar regions – an arena for male heroism

Few women visited the polar regions around the time that Brit took part in the expedition. If we look back at the 19th and early 20th centuries, the golden age of polar heroes, the polar regions have traditionally been reserved for bearded men. Polar history is largely about men, about who was the first, who discovered what and heroic stories about the survival of these men in demanding natural conditions.

BRIT'S GRAVE "Geologist Brit Hofseth 24 years old" is inscribed on Brit's gravestone in Tromsø Cemetery. *Photo: Anka Ryall / Norwegian Polar Institute*

When women like Brit Hofseth finally visited the polar regions, primarily as scientists rather than explorers, did they then challenge the stereotype of the polar regions that was reserved for male heroism?

"We see a duplicity. While female polar scientists were looking to observe the polar regions, they were so unusual that they themselves became the subject of the judgemental and critical gaze of others. The participation of women has thus undermined the myths of the Arctic as an arena exclusively reserved for male courage and heroism," says Ryall.

NY-ÅLESUND Climate change is leading scientists from many countries to visit Kongsforden near Ny-Ålesund in order to study the full effects of the environmental changes that are taking place in the Arctic. *Photo: Geir Gotaas / Norwegian Polar Institute*

NATURE'S WAY An Arctic fox has secured a meal amongst the birds nesting on one of the tiny islands in Kongsfjorden. *Photo: Geir Gotaas / Norwegian Polar Institute*

Elin Vinje Jenssen ——— *Norwegian Polar Institute*

50 years of research on land and water in Ny-Ålesund

Climate change is making major inroads into the natural environment on the northwest coast of Svalbard.

AN ARCTIC FOX AND A POLAR BEAR lurk close to the birds, both in search of food in the birds' nests.

In the innermost reaches of the fjord is the Kronebreen glacier. In front of this glacier, seals, whales, seabirds and other animals gorge on the zooplankton that live in the brown-coloured meltwater which rises up in front of the toe of the glacier.

Several degrees warmer

Kongsfjorden is one of the lushest fjords in Svalbard, with its climax during the summer. That is when the many diverse species appear at the surface. The mountainsides are coloured bright green by vegetation, due to rich occurrences of vascular plants fertilised by fulmars, kittiwakes, puffins and other seabirds. On the tiny islands, eider, geese and Arctic tern breed, while Svalbard ptarmigan and Arctic skua are a common sight on land. However, behind the veil of bustling life, the situation is serious. The Arctic is warming three times as fast as the rest of the world.

Since the early 1970s, the average temperature in Svalbard has risen by between 3–5°C. That is a lot for a place where cold and ice have provided the very foundations for ecosystems. The warmth has caused worrying changes in ecosystems, both on land and at sea.

No untouched idyll

Kongsfjorden is at the centre of the ongoing climate change. At this outpost on the northwestern coast of Svalbard, the effects of the warmer climate are already clearly visible. The water in the fjord changed from cold to warm over the period 2006-2008. Since then, Kongsfjorden has mostly been ice-free, even during the winter.

Winter rain

Winter rain now occurs annually in Kongsfjorden, while just a few years ago it was common only every three to four years.

Climate change is leading scientists from many countries to visit Kongsforden in order to study the full effects of the environmental changes that are taking place in the Arctic. The focus of this research is Ny-Ålesund Research Station.

Some of the research scientists are studying animals and plants, while others are focussing their attention more on the pollution which is increasingly reaching the Arctic and Ny-Ålesund via wind and ocean currents from industrialised countries further south.

Icy slopes

The herbivorous Svalbard reindeer is visible proof of how climate change is becoming established in the natural environment. It can be found in practically

DECLINING NUMBERS The number of Svalbard reindeer on the Brøggerhalvøya peninsula has declined by a third since the 1990s. *Photo: Sophie Cordon*

all areas which are not covered by glaciers. There, it lives close to the plant life, which is its only food.

The increasingly mild weather brings with it rain – and icy slopes. Since the late 1990s, "locked" pastures have become the norm rather than the exception. *"When rain freezes to form ice on the ground, a shield is formed which protects the vegetation from the herbivores which feed on it. Herbivore populations then take a knock as the wet winters increase in frequency,"* explains researcher Åshild Ønvik Pedersen from the Norwegian Polar Institute.

A warning from the tundra

Since the monitoring of Svalbard reindeer began four decades ago, the rise in temperature in the archipelago has accelerated.

In an article published in 2022 in the Norwegian Polar Institute's journal, Polar Research, Ønvik Pedersen and his research colleagues describe the close links between ecosystems in the Ny-Ålesund area over the past fifty years.

A number of the studies on which the researchers based their analyses form part of short and long time series which describe wildlife, vegetation, glaciers and changes in sea ice and temperature in Ny-Ålesund, some of which cover a time span of several decades.

Local differences

It is on the Brøggerhalvøya peninsula, on which Ny-Ålesund is located, that the mild weather has resulted in the most extensive areas of ice-covered pastures for the reindeer. This has had consequences for the population, which has been reduced by a third since the 1990s.

However, the situation is less serious in the large valleys of Nordenskiöld Land, where Longyearbyen is located. In this area, plant growth is increasing in line with the warming and providing plenty of pasture for the reindeer. The summer now starts several weeks earlier than it did a few years ago, and the animals that live here can continue to fatten themselves up for a harsh winter ahead until well into autumn. As a result, the reindeer population around Longyearbyen has almost quadrupled since 1979.

Monitoring set to be intensified

The long time series make it possible to analyse and understand the causes and effects of changes in the natural environment around Ny-Ålesund. However, there are also some gaps in our knowledge which the researchers are seeking to fill. In particular, they recommend maintaining and intensifying monitoring for a number of groups, including insects, microbes and freshwater fauna and flora,as they believe that monitoring should be integrated into the ecosystem-based monitoring programme under the auspices of COAT and SIOS. This will improve our understanding of the impact of changes in the environment across ecosystems and species groups.

"Understanding how these changes affect the entire ecosystem, from bottom to top, requires long-term monitoring and further research, as we have stressed in the article. Ny-Ålesund has the characteristics we need in order to fill these knowledge gaps," says Ønvik Pedersen.

INDUSTRIAL HERITAGE The mine locomotive in Ny-Ålesund still stands as a reminder of the past. *Photo: Geir Gotaas / Norwegian Polar Institute*

From coal to research

Ny-Ålesund was originally established as a result of coal mining in the area in 1916. Over the years that followed, the site also became the starting point for several attempts to reach the North Pole, including the attempts by Roald Amundsen and Lincoln Ellsworth using the flying boats N 24 and N 25 in 1925 and the airship Norge in 1926 – together with Umberto Nobile, as well as the attempt by Nobile in 1928 using the airship Italia.

However, a major mining accident in 1962 led to the end of mining, and just five years later Ny-Ålesund was established as a centre for international Arctic research and environmental monitoring.

In 1968, the Norwegian Polar Institute established itself with a year-round presence in Ny-Ålesund. In the years that followed, observations were made in seismics, the Earth's magnetic field, the Northern Lights and glaciology, to mention just a few fields of study. In 1989, the Norwegian Polar Institute moved into a new building: Norwegian Polar Institute Sverdrup.

Today, many institutions make extensive use of Ny-Ålesund, with research activity reaching a peak during the summer. Twenty institutions are conducting long-term research and environmental monitoring in and from Ny-Ålesund. Cooperation across nationalities is coordinated through the Ny-Ålesund Science Managers' Committee (NySMAC) under four programmes: The Kongsfjorden system (marine ecosystems), Terrestrial ecosystems, Atmospheric research and Glaciology. Kings Bay AS operates the site, while the Norwegian Polar Institute is both the host and the largest user, carrying out its own activities and assisting other institutions.

Photo: Hallvard Strøm / Norwegian Polar Institute

Knowledge 2021

The work of the Norwegian Polar Institute is focussed on strengthening the knowledge base in areas where the environmental administration has direct management responsibility in the northern and polar regions, or where i t plays a pivotal driving role in national and international processes, specifically within the fields of ***natural diversity***, ***pollutants*** and ***climate***.

Our knowledge acquisition is organised under four programmes: *The Svalbard programme*, *the Arctic Ocean programme*, *the Antarctic programme* and *the Ny-Ålesund programme*. The aim is to combine the research and consultancy activities to ensure that the Institute delivers relevant high-quality research and advice in line with its remit, and that all our activities are anchored in the Institute's values: credible, targeted, quality-conscious and forward-looking.

Through monitoring, research and investigations, *the Svalbard programme*, *the Arctic Ocean programme* and the *Antarctic programme* will produce data and knowledge to advise the management regarding the status, variability and development trends in the natural environment and ecosystems in their respective geographical areas, and knowledge concerning the drivers behind the changes. *The Ny-Ålesund programme* has been given responsibility for performing the role of host at Ny-Ålesund Research Station and implementing and following up the research strategy for the station. The programme will also help the Institute to deliver relevant research and advice.

The knowledge that is generated through the programmes forms the basis for our advice to the authorities for use in national management and international agreements, and is disseminated in scientific forums and to the general public.

In the following pages, we summarise some highlights from 2021, in some cases with a link to the original publication or website (in the online version) for further reading.

SEA ICE STUDIES A helicopter measures the thickness of sea ice on the Arctic Ocean using an electromagnetic instrument during the winter expedition of 2021 as part of The Nansen Legacy project. A number of researchers and technicians from the Norwegian Polar Institute took part. *Photo: Adam Steer / Norwegian Polar Institute*

Arctic

Major research projects

The Nansen Legacy

Large-scale Norwegian research project studying what will happen when the sea ice melts and the northern Barents Sea opens up. The Norwegian Polar Institute is playing a pivotal role in the management and execution of the project. The project carried out numerous cruises in 2021. During the year, the Research Council of Norway conducted a midway evaluation of the project. Website: www.arvenetternansen.com

EU projects

The Norwegian Polar Institute is a key player in two EU projects which commenced during the summer of 2021. These are “Pan-Arctic observing System of Systems: Implementing Observations for Societal Needs” (Arctic PASSION), which will contribute to the establishment of a holistic, pan-Arctic observation system for land, oceans and cryosphere, and "Climate Relevant Interactions and Feedbacks" (CRiceS), which will particularly investigate the role that sea ice and snow play in the global climate system in both the Arctic and Antarctic. Websites: https://arcticpassion.eu and https://www.crices-h2020.eu

COAT is developing integrated monitoring of the terrestrial system in Svalbard. The research equipment that has been deployed by the project will expand tundra monitoring through the addition of further data series, with the coupling of biota and physical drivers, in order to distinguish key potential causes of change (climate or management measures, etc.). This is being continued through the Institute's Svalbard programme. Website: https://www.coat.no

SEATRACK is mapping the spatial distribution and movements of Norwegian seabirds outside the nesting season and monitoring populations from neighbouring countries that enter Norwegian waters. Phase I of the programme was completed in 2018, but continued for a further four years (2019-2022). Phase II has been expanded to include colonies in Ireland, western Scotland, Greenland and Canada. The 2021 field season was successful in all eight countries which took part in the cooperation, except for the Arctic part of Canada, where fieldwork was not possible due to the ongoing pandemic. In 2021, a special edition of the scientific journal "Marine Ecology Progress Series" (MEPS) was published with articles presenting results from SEATRACK. Continuation of the programme after 2022 is planned and an application is under preparation. Website: https://seapop.no/en/seatrack

Marine mammals and habitats under pressure

The reduction in areal extent and thickness of sea ice is one of the most dramatic consequences of global warming, and this change in the physical environment is driving many ecosystem changes in the Arctic. All indigenous Arctic marine mammals, for example, depend on the sea ice for virtually every aspect of their life cycle. Hamilton et al. (2021) used tracking data from 13 different marine mammal species from the Barents region (seals, whales and polar bears) during the period 2005-2018 to identify areas that are particularly important for these species (and other species). The study showed that the marginal ice margin zone in the northern Barents Sea area, coastal areas in Northeast Greenland and all of Svalbard are important areas for the various species concerned.

Llobet et al. 2021 shows that the lack of concurrence between the breeding season and access to ice, combined with limited vocalisation in the middle of the mating season, indicates a marked decline in the presence of bearded seals in Kongsfjorden in Svalbard. Hamilton et al. (2021) identify areas that are of particular importance for 13 different marine mammal species from the Barents Region in the marginal ice margin zone in the northern Barents Sea area, coastal areas in Northeast Greenland and across all of Svalbard. The sea ice changes are likely to lead ringed seals to seek alternative habitats where possible (Vacquie-Garcia et al., 2021). Kovacs et al. (2021) found five distinct size groups for each gender of ringed seal, with the very largest ringed seals being found in northern Canada and Western Greenland. In a study of the age, growth, condition and reproduction (demographics) of ringed seal on the west coast of Svalbard, Anders et al. (2021) explains that the parameters did not change dramatically between 1981 and 2018, despite the reduction in fjord ice throughout the period.

During the period 2005-2018, there was a marked shift northwards amongst polar bear, bearded seal and harp seal during the summer, as well as more frequent sightings of harbour seal in the fjords on the western side of Svalbard. Ringed seal and polar bear continue to inhabit areas with ice, but both polar bears and walruses are also returning to their former habitats in Svalbard, as numbers rise following protection (Bengtsson et al., 2021).

LESS ICE Bearded seal are strongly linked to areas with ice. During the past ten years, there has been a shortage of sea ice in some of the fjords on the western side of Spitsbergen, and the seals have used ice which has calved from the glaciers as a birthing and suckling platform. However, this is a short-term solution, as glaciers in Svalbard are generally shrinking due to global warming. *Photo: Ann Kristin Balto / Norwegian Polar Institute*

Blanchet et al. (2021) provide further support for the assumption that harbour seal will continue to spread northwards in the Arctic, despite regional differences in the current effects of temperature rises in the north. Ringed seal and harp seal have different diets, but ice-associated prey is important for both species. Ongoing climate change is likely to have a major impact on their diets (Kunisch et al., 2021).

Tryland et al. (2021) presents the results of samples taken from healthy bearded seal living at the Polaria experience centre (in Tromsø) and from wild bearded seal in Svalbard, with the aim of determining normal blood values in bearded seal.

The use of sensors which are attached to animals and document oceanographic conditions in the waters in which the animals live and migrate has improved access to oceanic data, especially in polar regions, where traditional sampling is hindered by ice cover and harsh weather conditions, explains McMahon et al., 2021. Humpback whales remain in northern marine areas for longer into the spring than previously thought, as demonstrated by Martin et al., 2021.

Cubaynes et al. (2021) have created a model which can be used in future analyses of how various factors, including a warmer climate and the loss of sea ice, will impact on survival and reproduction amongst polar bears.
Brown et al. (2021) found that 17 adult polar bear females who remained in Svalbard during the period 2011-2019 migrated seasonally within the archipelago, and that they spent most of the year either in a local fjord or in a limited area on one of the islands.

Stempniewicz et al. (2021) reported a number of recent incidents where polar bears have hunted and, in some cases, caught reindeer.

Planned flights based on our knowledge of species-specific tolerance limits could help to reduce any negative impacts of drone use, according to Palomino-Gonzalez et al. (2021). They studied the effects of drone use on harbour seal and walrus on their haul-out sites, and on beluga whale and polar bear. The response of the animals to drones was influenced by tidal and wave heights, whether there were juveniles in the groups, and general noise levels from the surroundings.

Maduna et al. (2021) explored genetic differentiation and diversity amongst 626 polar bears in four different areas of Svalbard from 1995 to 2016. During this period, genetic diversity declined by 3-10%, while the genetic difference between areas increased by 200%. These changes can best be explained by a reduction in the exchange of polar bears between areas and more inbreeding within areas caused by the reduction in the ice sheet.

Changes in the environment as a result of global warming and increased human activity represent a potential threat to marine mammals in the Arctic. Being able to identify both hotspots and areas of high species diversity amongst marine mammals in this area constitutes essential knowledge with the aim of ensuring good management practices and where appropriate initiating conservation measures, a view which Hamilton et al. (2021) supports in the study based on the satellite tracking of 13 species of marine mammals in the Greenland and Barents Sea areas during the period 2005-2018.

Due to the major changes taking place in the Arctic as a result of global warming, significant changes in terms of both time and space are expected in the distribution of marine mammals. In a study using passive acoustic listening buoys in Arctic areas of the Northeast Atlantic, the presence of blue whale and fin whale was recorded. These species are also believed to be seasonal visitors to the Arctic (Ahonen et al., 2021). Two of the listening buoys were located in the Fram Strait (about 95 km apart), while the third was located north of Svalbard.

FIN WHALE Biologists take a biopsy from a fin whale off Prins Karls Forland in Svalbard for research in connection with genetics, diet and pollutants. *Photo: Nick Cobbing / Norwegian Polar Institute*

Bowhead whales from the Spitsbergen population almost became extinct as a result of historical hunting and are today classified as "critically endangered". From a management perspective, it is therefore important to know whether this is actually a separate entity or part of a larger population. Bachmann et al. (2021) studied the population's demographic history and the potential differentiation between whales from different regions. Many species of Arctic marine mammals are expected to be adversely affected by the ongoing rapid changes in the ice distribution as a result of global warming, but the consequences for beluga whale are somewhat less certain due to the fact that they exhibit more flexible adaptation across their extensive distribution range. In order to study how this species will respond to changes in the future, Skovrind et al. (2021) studied how they have responded to climate variations in the past. Forecasts for the year 2100 show that suitable habitats for beluga whale in particular will be reduced in extent in southern parts of their current distribution range, and that they will gradually move northwards as the ocean continues to warm. Population figures are expected to decline.

Lydersen and Kovacs (2021) compared data concerning beluga whale in Svalbard from satellite tracking from two different periods (1995-2001 and 2013-2016). The results show that these whales have an extremely coastal distribution and spend most of their time foraging close to glacier fronts. When they move, they do so quickly, and they often follow the coastline from one glacier front to the next. Furthermore, beluga whales in Svalbard have extremely high levels of many pollutants, and climate change is also a threat to these animals. This article forms part of a special edition of Polar Research which includes a series of works on beluga whale and encompasses knowledge concerning wild whales, whales in captivity and local knowledge from various indigenous peoples (see the introductory chapter to Kovacs et al., 2021).

A number of researchers at the Norwegian Polar Institute have contributed to an article (Steiner et al., 2021), which summarises the characteristics of sea ice ecosystems and the way in which sea ice as an ecosystem contributes to ecosystem services. The review shows that sea ice contributes services from all four categories of ecosystem services: producing (e.g. food harvesting), supportive (e.g. as a habitat for important species), regulatory (e.g. climate regulation) and cultural services. The sea ice ecosystem also fulfils the criteria for biologically important areas. The most important measure to prevent loss of the sea ice habitat and associated services is to reduce carbon emissions.

Fewer Arctic seabirds

The major changes taking place in the marine environment are impacting on seabird populations. In a major study published in "Ecology", based on long-term monitoring data from nine of the most common seabird species in Svalbard, Descamps and Strøm (2021) found that populations of species that primarily nest in temperate environments are increasing in Svalbard, while populations of Arctic species are in decline. This process is known as "borealisation", warming of the ocean and air to a level that is higher than has previously been characteristic of Arctic marine areas, as a direct consequence of global warming.

Frederiksen et al. (2021) used long time series from 12 thick-billed guillemot colonies in Svalbard, Iceland, Jan Mayen, Bjørnøya, Greenland and Canada to analyse breeding success, survival and trends in population sizes, and found that colonies in the east, including Svalbard, have exhibited a negative population trend, while colonies in the west are stable. It is concluded that the decline that has been observed is the result of low survival rates amongst Brünnich's guillemot young, which may be linked to poor food availability.
Descamps and Ramirez (2021) looked at the relationship between sea ice distribution and changes in the size of Brünnich's guillemot and kittiwake colonies in Svalbard, and concluded that changes in population size in Brünnich's guillemots and kittiwakes are not due to the reduction in ice in the coastal areas around Svalbard.

Merkel et al. (2021) conclude that Brünnich's guillemots are geographically very restricted as regards where they overwinter, and that they are likely to be adversely affected by changes in the geographical distribution of their prey. Hansen et al. (2021) found a non-linear relationship between sea temperature and puffling (puffin chick) production in Iceland, which may indicate that last year's decline in young production is due to a rise in sea temperature.

PLENTIFUL, BUT VULNERABLE The little auk is the most numerous bird species in Svalbard. However, even this species will be adversely affected if the temperature continues to rise, because the warming of the ocean is changing the birds' access to food. *Photo: Sebastién Descamps / Norwegian Polar Institute*

Strøm et al. (2021) introduced four main themes for the SEATRACK seabird programme in the "Marine Ecology Progress Series" (MEPS): 1) variation in migration strategies amongst individuals, populations and species; 2) the relationship between winter distribution and population development/demographics; 3) significance of winter distribution for the uptake of pollutants, and 4) the use of tracking data in marine planning. Through to 2020, a total of 14,535 loggers were placed on birds from 11 species, and data from 5,440 loggers was collected and downloaded. In the same edition of MEPS, Fauchald et al. (2021) describe the implications of SEATRACK for the future management of seabirds. Dufour et al. (2021) explored the potential consequences of the variations in migration strategy for the breeding success of little auk colonies in Svalbard and conclude by identifying two key wintering grounds: north of Iceland and around southwest Greenland.

The marine areas around Iceland are an important wintering ground for little auk from Svalbard, and to a lesser extent for little auk from Frans Josef Land. Use of the same wintering grounds did not synchronise survival rates between the different populations, indicating that the survival rates of little auk are not only affected by the environmental conditions in their wintering grounds, according to Descamps et al., 2021.

Amelineau et al. (2021) used a new method to identify active migration periods in six pelagic seabird species. Between two breeding seasons, the birds had an average of three to four migratory periods, and two to three periods where they remained in the same area for a long period of time. During the migratory periods, all species continued to eat and rest using a "fly-and-eat" strategy. Habitats used by seabirds during their migrations are therefore important not only as overfly areas, but also as areas where they can find food.

Surprising results from Ezhov et al. (2021) showed that six out of a total of 27 kittiwakes from a breeding colony situated south of Novaya Zemlya wintered in the Pacific Ocean. The birds that wintered in the Pacific Ocean were followed over a period of several years, and the strategy of migrating eastwards after the breeding season did not change between years. This two-part migration strategy is explained by the migration history of the species, with two subspecies originating from different locations.

Tidewater glacier fronts can be important nutrient areas for Arctic marine birds and mammals, but this important habitat is in decline due to global warming. Bertrand et al. (2021) documents that kittiwakes in Kongsfjorden used glacier fronts less than 18 km from their nesting site, although some kittiwakes flew almost 300 km from the colony. Bertrand et al. (2021) confirmed annual variations in the use of glacier fronts by the kittiwakes.

Merkel et al. (2021) showed that 13 guillemot and Brünnich's guillemot colonies in the Northeast Atlantic have a strong connection to specific geographical areas. In a situation where the environment is changing rapidly, what have so far been favourable habitats can change so rapidly that species such as Brünnich's guillemots and guillemots do not have time to adapt their migration strategies.

More frequent storms are a feature of global climate change, and there is some concern regarding seabirds because winter storms are linked to higher mortality rates. Clairbaux et al. (2021) combined data on winter distribution for five of the most numerous seabird species in the North Atlantic. The results show that, although severe winter storms affect birds from all five species and all sub-populations that were studied, species and populations which overwinter in the Labrador Sea, the Davis Strait, around Iceland and in the Barents Sea are particularly vulnerable.

Another concern that follows from accelerating changes in natural environments is the potential for the overlapping of human resource use with animals. While sea ice used to be a natural barrier to human activity, a study by Dupuis et al. (2021) shows that 88% of 336 fulmars from 12 colonies in the Northeast Atlantic and the Barents Sea were exposed to artificial light at least once outside the breeding season.
Mercier et al. (2021) described 'divorce' rates amongst partners in five seabird species nesting in polar regions. Four had very low divorce rates, but divorce was more common in kittiwakes, where it depended on previous breeding success. Divorcing following unsuccessful breeding can be one way of finding a better partner and improving the chances of future breeding success.

Puffins in the North Atlantic comprise four main populations/clusters, and puffins in Svalbard are clearly different from other populations, as Kersten et al. (2021) confirm. Puffins from Bjørnøya are genetically located between the population of Spitsbergen and a larger group consisting of birds from Norway, Iceland and the Faroe Islands.

Measures to preserve biodiversity can be implemented on many scales – from local to global. Clairbaux et al. (2021) examined how the goal of the Paris Agreement to limit global warming to less than 2°C will impact on the winter distribution of seabirds in the North Atlantic. The study showed that, by reducing warming, changes in habitat selection and area use can be significantly reduced, which would have a major impact on the conservation of North Atlantic seabird populations.

The northern part of the Atlantic Ocean has some of the largest seabird populations in the world. This study by Clairbaux et al. (2021) looked at the significance for the future winter distribution of seabirds in the North Atlantic of achieving the Paris Agreement's goal of limiting global warming to 2°C. Current and future winter distributions for five key seabird species (kittiwake, guillemot, Brünnich's guillemot, little auk and puffin) were described and modelled using tracking data from approximately 1,500 individuals, combined with data on their habitat use, diet and energy consumption. The results show that the winter distributions of these species will change as a result of climate change.

OVERWINTERERS Only four warm-blooded animal species overwinter in Svalbard: Svalbard reindeer (pictured), Svalbard ptarmigan, Arctic fox (pictured) and East European vole. *Photo: Sophie Cordon / Norwegian Polar Institute*

Overwinterers on the tundra

Only four warm-blooded animal species overwinter in Svalbard: Svalbard reindeer (pictured), Svalbard ptarmigan, Arctic fox (pictured) and East European vole. Garfelt-Paulsen et al. (2021) describe how reindeer doe with and without calves used the habitats in Svalbard in a similar way, but doe with calves tended to be somewhat more locally restricted between years and chose areas with the best access to food. Another reindeer study (Loe et al., 2021) concludes that warmer weather in autumn has a positive effect on population viability, which can compensate for bad winters. Furthermore, data from the monitoring of Arctic fox dens, age upon being caught, foetal marks in the womb, and marking-recapture collected over a period of 22 years shows that the Arctic fox population has remained reasonably stable in Svalbard (Nater et al., 2021). Marolla et al. (2021) used long time series from the Norwegian Polar Institute and COAT to study how climate change is impacting on the population development of the Svalbard ptarmigan.

In order to distinguish natural variations from changing environmental conditions amongst vascular plants, mosses and soils in various tundra habitats, long-term monitoring will be necessary, according to Petit Bon et al., 2021. Previous grazing affects low Arctic tundra landscapes more than 60 years later, according to Mosdorf et al. (2021), who illustrate the importance of long-term monitoring. No corresponding data is available for High Arctic areas, but a map developed by Soininen et al. (2021) could be a good starting point for identifying key areas where such studies should be carried out.

Barrio et al. (2021) developed protocols for studying the influence of herbivores on arctic tundra in the North American Arctic, Greenland, Svalbard, the Russian Arctic and subarctic/alpine regions of Europe. Other new methods published in 2021 include the development of a workflow for the drone mapping of tundra vegetation, Eischeid et al. (2021).

Non-native species

A warmer climate increases the risk of non-native species becoming established in Svalbard. The East European vole is currently the only non-native mammal species to have gained a foothold in Svalbard. Fauteaux et al. (2021) document that variations in the vole population in Svalbard are driven by climate change, and that further warming of the climate will reduce the area of grazing land covered by ice and lead to more frequent peak years for voles, especially close to human settlements. In the plant kingdom, 36 non-native plant species have been found in the most comprehensive mapping of Svalbard to date. These species are found in settlements, especially in areas with current or past human activity, while none are found on bird cliffs. A method that can be used as part of monitoring strategies for non-native species in the Arctic was described by Bartlett et al. (2021) and submitted to the Ministry of Climate and Environment. This study is based on findings from previous assignments given to the Norwegian Polar Institute in letters of allocation and by the Governor of Svalbard. Mellard et al. (2021) also looked at the factors that are important in the monitoring of land-based ecosystems. The study shows that it will be necessary to combine long-term monitoring of the food web on land with models of sufficient complexity if the way in which populations respond to environmental changes and harvesting is to be understood.

Pollution and plastics in the ocean

Although the Arctic is a long way from many major sources of pollution, water and air currents bring significant amounts of pollutants into the ecosystems of the High North. Albert et al. (2021) explain how some species of Arctic seabirds are being polluted by mercury. Leslie et al. (2021) found that levels of pollutants in glaucous gull eggs from Bjørnøya were higher in the last year of the study than previously, but still lower than in birds from Central Europe. Positive correlations have been found between some PFAS compounds and thyroid hormone in kittiwakes in Svalbard (Ask et al., 2021). Routti et al. (2021) detected the pollutant DEHP in whale samples and cases where levels in blue and fin whale blubber were equal to levels of known pollutants such as PCBs and organic pesticides. The decomposition product of phthalates was found in low concentrations in a few polar bear samples.

The ingestion of plastic by Arctic animal species is a recurring problem according to Collard and Ask (2021), who combined existing knowledge concerning both marine and terrestrial species throughout the food chain. Collard et al. (2021) studied a total of 68 sediment samples from five sites along a transect from the outlet of the sewer pipe from Ny-Ålesund to the shelf edge and found 37 man-made particles, of which 19 consisted of microplastics. Most particles were found in samples collected from the mouth of Kongsfjorden; the least polluted sites were on the shelf and around the sewer outlet for Ny-Ålesund.

Lusher et al. (2021) present a Norwegian perspective on research concerning microplastics. The problem of plastic in the ocean was presented to a younger audience by von Friesen et al. (2021). Neumann et al. (2021) studied polybrominated diphenyl ether (PBDE) which is found in plastic and ends up in the liver tissue of animals which eat plastic.

Aluru et al. (2021) show that the genes linked to cholesterol and fat metabolism were affected by exposure to the PFRs in cod liver. These genes are also linked to physiological processes such as reproduction, growth and temperature adaptation.

In the study by Pascoal et al. (2021), the researchers explain, using data from the N-ICE2015expedition, how the rare prokaryote biosphere in the Arctic Ocean north of Svalbard varies with very different environmental conditions from winter to early summer.

FINE-COMBED LAND Scientists found 36 non-native plant species in a comprehensive plant survey of Svalbard. These were found in settlements, especially in areas with current or past human activity. This plant, from the buttercup family, was found in Pyramiden. *Photo: Virve Ravolainen / Norwegian Polar Institute.*

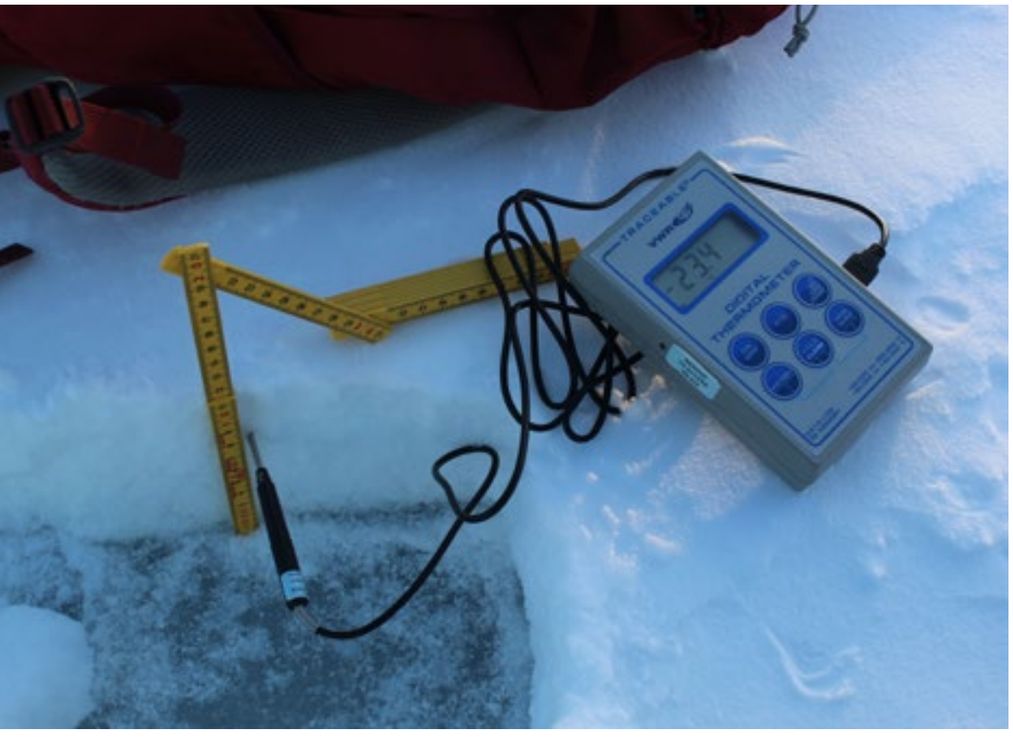
Climate, sea and sea ice

Researcher Gary Griffith from the Norwegian Polar Institute shared his thoughts on climate change on the tenth anniversary of the journal Nature Climate Change. The main conclusions of this initiative were that society must be prepared for sudden and unexpected changes in marine resources, an increase in the potential for tipping points and alternative stable states, and the emergence of new adaptations and evolutionary strategies (for details, see Eyring et al. (2021)).

Gamboa-Sojo et al. (2021) developed a method based on living and dead foraminifera, microscopic marine animals that live on the seabed, which can be used for environmental and climate surveys. They did not immediately find any major changeson the seabed, but the data indicates that changes are taking place in the fauna as a result of warmer water.

Mellat et al. (2021) and the research network "Pan-Arctic Precipitation Isotope Network (PAPIN)" will establish a target for the amount of precipitation that is of Arctic origin and the amount that originates from lower latitudes, which will enable any changes in the Arctic water cycle to be studied in the future.

The occurrence of methane in Arctic fjords is affected when there is less sea ice, and because methane is a much more potent greenhouse gas than carbon dioxide, it is important to find out more about how climate change impacts on emissions of methane from the ocean into the atmosphere. Damm et al. (2021) showed, using measurements of dissolved methane concentrations, that the entire water column in Adventfjorden and Tempelfjorden was oversaturated all year round in Svalbard between 2015 and 2017.



ICE STATION Measurement of sea ice thickness, snow thickness and temperature during cruises to the Arctic Ocean in winter 2021. *Photo: Sebastian Gerland / Norwegian Polar Institute*

ICE MASS BALANCE Glaciologist Emily Geyman carrying out fieldwork on the Holtedahlfonna glacier in Svalbard, aimed at measuring the mass balance. The mass balance of a glacier is the difference between growth due to precipitation in winter and reduction in summer as a result of melting and runoff. *Photo: Stein Tronstad / Norwegian Polar Institute*

Glaciology – Present and Past

Light-absorbing, carbon-containing aerosols produced through the combustion of biomass or fossil fuels can amplify climate warming in the Arctic by lowering the albedo of the snow, according to Zdanowicz et al. (2021). Bertò et al. (2021) describe daily variations in levels of Black Carbon (BC) on the surface of the snow in Ny-Ålesund. The study concludes that overall concentrations have remained relatively consistent over time, and that variations in concentrations of BC are directly linked to precipitation.

Snow in the southern part of Svalbard contained high overall concentrationsof ions (electrically charged atoms), according to Barbaro et al. (2021). A very important practical implication from this study is that the optimal locations for studying the effects of long-range transported pollution in Svalbard are high-altitude glaciers, because they are least affected by localised aerosol emissions. Spolaor et al. (2021) presented the first thorough evaluation of the water-soluble fractions of trace elements on Hansbreen glacier in southern Svalbard, and found that the chemical composition of the glacier is primarily influenced by summer transport and deposition, and is not affected to any great extent by melting of the snow layer on the glacier.

Abraham et al. (2021) present the largest data set of pollen traps to date, consisting of 351 trap sites with a total of 2,742 annual samples covering the period from 1981 to 2017. They found an increasing trend in pollen accumulation of trees (pine) in Northern Scandinavia due to higher temperatures and pollen production. One of the traps in the data set is located at Ny-Ålesundand has been in use since 2009.

Svalbard has a complex geological history. Analyses of geochemical elements in neighbouring areas can provide an insight into the formation of the archipelago. Bazarnik et al. (2021) analysed the main and trace elements in amphibolite and ultramafic rocks in Ny-Friesland in northeast Svalbard, and concluded that the occurrence of ultra-mafic rocks in the upper part of the Atomfjella Complex does not represent a tectonic contact between two crustal blocks, as previously thought.

Marine primary production

Primary production is the basis of the marine food chain. In the Arctic, primary production is limited by light and nutrient availability. In recent decades, primary production in the Arctic has increased, due to increased light intensity as a result of reductions in sea ice cover. How much primary production will increase by ultimately depends on the availability of nutrients. Duarte et al. (2021) found that concentrations of nutrients in water masses in the European Arctic have not changed significantly, except for a reduction in silicate concentrations in surface water.

Phytoplankton blooms in areas with sea ice are expected to start earlier and occur further north as the sea ice cover decreases and becomes thinner. For the first time,data concerning developments in phytoplankton-were compiled for the sea ice zone north of Svalbard from winter to late summer, using short-term sediment traps. Dybwad et al. (2021) observed a marked seasonal pattern, with low phytoplankton biomass and export flux during the winter and before blooming, a brief and intense productive season in May and June, and low phytoplankton biomass with moderate export flux after blooming in late summer. In the past, the marginal ice margin zone has been considered to be one of the most productive marine areas, but this study shows that intense blooms and high export can also occur in ice-covered waters.

Hop et al. (2021) analysed data from six months of observations of zooplankton under sea ice from the N-ICE2015 expedition over the Nansen Basin and the Jermak Plateau north of Svalbard. Despite a late start to the spring bloom due to the presence of densely packed ice, both the North Atlantic and Arctic species reproduced. This explains the species-rich meso-zooplankton community in this region compared with the less productive central Arctic Ocean. Reduced sea ice cover and the earlier start of the bloom, which is indicated by forecasts of future developments, are likely to have a positive impact on the overall secondary production of both Arctic and boreal species of zooplankton in this region.

NUTRIENT-RICH FOOD Kittiwakes gathered next to a glacier front in Kongsfjorden, Svalbard, in search of marine organisms in the water. *Photo: Geir Wing Gabrielsen / Norwegian Polar Institute*

UNDER THE ICE Ice station off Nordaustlandet in Svalbard during the plastic cruise in the summer of 2021. Marine biologist and research diver Haakon Hop is ready to dive under the ice to collect samples of ice algae and crustaceans. He is assisted by research diver Frode Gerhardsen.
Photo: Trine Lise S. Helgerud / Norwegian Polar Institute

A pan-Arctic analysis by Hop et al. (2021) of data concerning ice-associated amphipods and mysida, using material covering a period of 35 years (1977-2012), showed variations in species composition between the deep basins and shelf areas of the Arctic Ocean, and between communities in drift ice and land-fast ice.

Kohlbach et al. (2021) studied food web interactions for 24 species of zooplankton along a transect from the northern Barents Sea into the Arctic Ocean. The results help to improve our understanding of the ecological consequences for the food web in a Barents Sea with less and more variable sea ice.

Kohlbach et al. (2021) studied the dietary preferences of key zooplankton in light of the rapid warming of the Barents Sea. Arctic cod have a circumpolar distribution and are the most common pelagic fish species in the Arctic, but decreasing sea ice is directly impacting on the species and opening up the possibility of industrial activity in the region, with greater pressure on biota as a result. Aune et al. (2021) collate data concerning Arctic cod from the Russian sector of the Barents Sea and discuss knowledge gaps relating to the management of Arctic cod under changing environmental conditions and human influences.

Boreal species are spreading to Arctic marine areas as a result of global warming. A study by Frainer et al. (2021) looks at how this is altering the functional diversity of the ecosystem andwhat additional new ecosystem characteristics are leading to these changes.

A new study by Anglada-Ortiz et al. (2021) describes a survey of the occurrence of plankton foraminifera and pteropods at the edge of the slope between the Barents Sea and the Arctic Ocean, northeast of Svalbard. Both species contribute to the carbon cycle, but the contribution of pteropods
was significantly greater than that of foraminifera. This may be important in the event of increased ocean acidification. Ofstad et al. (2021) studied the density of the shells of planktonic foraminifera and pteropods in the Barents Sea, based on samples collected from the water column and the seabed. The results show that the shells of living organisms were not affected by biogeochemical processes, while those from dead organisms found in sediments had a reduced density.

Sea ice in the Arctic Ocean has become much younger and thinner over the past few decades. The sea ice in the Arctic as it was in 2020 and developments over time are discussed in a sub-chapter (Meier et al. 2021) in a comprehensive publication on the annual status of the world's climate. An important feature is that the trends are still negative as regards the distribution of ice in the Arctic, during both the winter and the summer. The distribution in summer (September) in 2020 was the second lowest annual minimum distribution observed since the first observations were made from a satellite in 1979. The winter distribution in March 2020 was the highest observed since 2013, but still the eleventh lowest annual maximum recorded since 1979.

Older multiyear sea ice makes a greater contribution to the snow cover on the ice than younger first-year ice (Lange et al., 2021). This difference occurs as the older ice accumulates more water from the snowmelt through several melting seasons. The meltwater freezes and contributes to the mass of the ice. When the older ice eventually melts, it releases fresh water that has accumulated over several years, far away from where it originated.

During the German MOSAiC expedition in the Arctic Ocean, a radiation model was used to investigate the effects of snow and ice properties on microwave signals (Demir et al., 2021). The study shows that lower-frequency microwaves are sensitive to the properties of snow and sea ice, especially salinity. This may mean that the use of such observations can provide a better insight into the properties of the ice.

During the same expedition, Semmling et al. (2021) studied sea ice with different thicknesses of snow cover, as well as the formation of open water around the ship.

In atmospheric research, re-analysed data sets are used, especially in areas with few observations, such as the polar regions. Di Biagio et al. (2021) use observations of weather, radiation, heat exchange and clouds made during N-ICE2015 to evaluate two important re-analysed datasets (ERA-Interim and ERA-5) and two data sets based on remote sensing using the CALIOP and CERES satellites. The results show important errors which are present in many (often all) of these data sets. The most important ones were incorrect surface temperature in winter, insufficient reflection of sunlight in spring and summer, and fewer clouds in summer than actually observed. All these factors are important when determining the heat balance, and thus the freezing or melting of sea ice. Both researchers and producers of these data sets are urged to be aware of this when developing and using the datasets. Rösel et al. (2021) look at the accuracy of snow radar measurements taken from the air. The authors note that the distribution of snow in the study area (in the Arctic) varied considerably between areas, suggesting substantial regional variability in snow thickness.

Cheng et al. (2021) have modelled the development of sea ice and snow in the Arctic Ocean during the drifting of the schooner Tara during the International Polar Year in 2007.

In a study by Katlein et al. (2021) , the researchers found that the light level in the ridges can be higher than in the surrounding undeformed ice. The light level in the sea ice is very important for algae.

Amongst other things, Mellat et al. (2021) found that around 68% of air masses which bring precipitation into the Arctic region during the summer originate from lower latitudes, while the remaining 32% of precipitation events come from northern air masses.

Stedmon et al. (2021) studied the distribution of different types of surface water masses in the Arctic Ocean, particularly the extent of water from the Pacific Ocean in relation to fresh water from Siberia. For the first time, Zamelczyk et al. (2021) present data concerning quantities of the calcareous zooplankton planktonic foraminifera and shell-building pteropods which live under the sea ice, as well as species composition and vertical distribution during the polar night in the Nansen Basin of the Arctic Ocean and the northern Barents Sea. Different water masses, conditions in the sea ice cover and ocean chemistry were important factors in determining the distribution of species.

A multi-year study of calcium carbonate ($CaCO_3$) saturation from the Svalbard shelf and the Atlantic Arctic Ocean (Jones et al. 2021) shows that the variation in the sea ice system, with varied dominance of Atlantic water or Arctic water, affects the biogeochemical processes which occur and carbonate chemistry, with the result that the Atlantic water or “Atlantification" can exacerbate or dampen acidification of the surface water.

Dong et al. (2021) found that if the sea ice melt during the summer and the resulting layering of the surface are not taken into account, annual CO_2 uptake in the Arctic Ocean can be underestimated by 6-17%.

FURTHEST NORTH In the autumn of 2021, a group of research scientists and technicians from nine Norwegian institutions travelled on a five-week cruise to the northern Arctic Ocean on the research vessel Kronprins Haakon, under the auspices of The Nansen Legacy project. The aim was to investigate the physical, chemical and biological consequences of global warming and the reduction in sea ice. On day 36, the ship reached the northernmost station on the cruise at a latitude of 87°31′ N, around 200 miles from the North Pole. Kronprins Haakon had never been so far north before. The expedition was led by marine scientists Agneta Fransson from the Norwegian Polar Institute (left) and Bodil Bluhm from UiT The Arctic University of Norway.
Photo: The Nansen Legacy and the Norwegian Polar Institute

Lundesgaard et al. (2021) look at whether years with a particularly small or large ice area in the Arctic Ocean are a direct result of particularly high or low sea temperatures, and confirms that the ocean heat content has a strong influence on sea ice concentration in the area. No evidence was found that variations in ice concentration between years during the observation period were primarily the result of fluctuations in sea temperature.

Analyses from Aaboe et al. (2021) confirm a substantial influx of sea ice in the Svalbard-Barents region in 2019 caused by winds from the north and the resulting movement of thick ice towards the Atlantic sector of the Arctic Ocean during the winter of 2018/2019.

Koenig et al. (2021) found that nonlinear internal waves driven by daily tidal currents can develop north of Svalbard and in the Laptev Sea and Kara Sea, with the potential to mix the entire water column vertically. A better understanding of the drivers behind turbulence and the nonlinear energy flow of turbulence in the Arctic Ocean will help us to understand the rapidly changing Arctic climate system.

Fossum et al. (2021) present the development and results of instrumentation on autonomous underwater vehicles which have been programmed to detect and measure an Arctic front. Wang et al. (2021) examine the contribution of different water masses to the export of heavy water which flows across the Iceland-Scotland Ridge to deeper parts of the North Atlantic, as a key part of the Atlantic overturning circulation.

Pieńkowski et al. (2021a) use biomarkers from fossil sea ice algae and plankton from marine sediment cores to reconstruct past sea ice variations northeast of Svalbard. The study clearly shows that sea ice has been continuously present northeast of Svalbard since the last ice age. Pieńkowski et al. (2021b) establish new radiocarbon calibration values for the Barents Sea and Svalbard in order to produce more precise marine climate archives.

GETTING WARMER The warmer global climate is also increasingthe pressure on nature in Antarctica. *Photo: Samuel Martínez Llobet / Norwegian Polar Institute*

Antarctica

Biodiversity

The warmer global climate is also increasing the pressure on natural resources in the Antarctic. For area-based management, it is important to have a good understanding of particularly valuable areas for species which shape ecosystems.

Kauko et al. (2021) observed regional differences in the timing and extent of phytoplankton blooms in the King Haakon VII Sea in the Southern Ocean. The results showed that the sea ice cover in the spring and grazing from zooplankton are probably important controlling factors for the bloom dynamics.

Handley et al. (2021) state that if the proposals for marine protected areas in the Southern Ocean currently being considered are adopted, the protected area of land consideredto be extremely important for penguins will increase by between 49 and 100%, depending on the species concerned.

Steiner et al. (2021) summarise the properties of sea ice ecosystems and how sea ice as an ecosystem contributes to ecosystem services.

Antarctic fur seals were split into two populations when the extent of the ice reached a peak during the last ice age. The populations later colonised the West Antarctic Islands and Bouvet Island in the west, as well as Kerguelen in the east, when these areas became ice-free. Future expansion of the distribution area of this seal species is likely to include more southerly areas than the current distribution, according to Cleary et al. (2021).

Satellite observations suggest that the phytoplankton biomass has increased over the past 20 years across most of the Southern Ocean. Over the next 100 years, Earth System Models (ESM) predict that production will increase in the water column in the Antarctic zone, but decline in the subantarctic zone (Pinkerton et al., 2021).

Ice and sea ice are important factors in determining primary production in the Southern Ocean, but there are substantial gaps in our knowledge concerning the details. Roukaerts et al. (2021) analyse a paradox observed in productive sea ice, where an accumulation of the macro-nutrients coincides with an accumulation of algae biomass.

Burgay et al. (2021) developed and used a new method for determining concentrations of Fe (II) iron in snow and firn samples from both the Antarctic (Dome C) and Svalbard (Holtedahlfonna). Iron concentrations were significantly lower in the samples from the Antarctic than in those from Svalbard. First and foremost, the results of this study provide a better insight into processes which are of relevance to Svalbard.

Light and access to nutrients affect the relationship between chlorophyll and carbon in phytoplankton in the ocean. Masuda et al. (2021) integrated a three-dimensional biogeochemical ocean circulation model for an improved interpretation of changes in phytoplankton as an effect of climate change. Núñez-Egido et al. (2021) conducted a study on seals in the Southern Ocean which has provided important background data for future assessments of changes in the pathogen load in these species.

Pollutants and pollution

At a general level, pollutants and pollution are less of a pressing problem in the Antarctic than elsewhere. Nevertheless, it is important to obtain a good overview of status and development trends in the South as well, so that the relevant management bodies have sufficient insight to raise the issue when necessary.

Hermansonn et al. (2021) studied the quantities and types of a number of pollutants in snow on a high-altitude glacier in Svalbard and at a location deep into the plateau in Antarctica. They found that Antarctica receives smaller quantities of virtually all the substances covered by the study. The study has improved our understanding of the complex processes relating to emissions, transport and degradation of the substances, and their uptake in ecosystems. Carravieri et al. (2021) show that levels of pollutants such as mercury and compounds of organo-chlorines are generally low in Antarctic petrels in Dronning Maud Land, and that pollutants do not affect their demographics. A study by Midthaug et al. (2021) shows that levels of pollutants such as PCBs were higher in south polar skua at Svarthamaren in 2013/2014 than in 2001/2002. Exposure in the Indian Ocean and the surrounding countries outside the breeding season may be the dominant source of pollutants in this migrating seabird.

In a Nature study which analysed ice cores from the Antarctic, a rapid increase in the deposition of Black Carbon (BC) dated to the year 1297 (±30) was observed, which coincides with the colonisation of New Zealand by the Māoris, when there was an increase in the combustion of biomass (McConnell et al., 2021). It is important to date historical changes in atmospheric BC and other products of biomass combustion in order to understand the radiation impact and the carbon contribution to the food chain.

ICE SHELF An ice shelf is the part of a glacier which floats on the sea. The ice can be more than 1,000 metres thick. In Antarctica, around 10 percent of drier land masses consist of ice shelf. Researchers at the Norwegian Polar Institute are studying how warmer oceans are affecting the ice shelves. *Photo: Julius Lauber / Norwegian Polar Institute*

Ocean and ice shelf

Global sea levels are rising and, to a greater extent than in the past, this is due to the loss of ice from Antarctica. An important dynamic in this context is the interaction between the ocean and the ice shelves, and it is here that there are significant gaps in our knowledge which must be filled if we are to gain a better insight into future developments.

A study by Janout et al. (2021) presents new oceanographic measurements from the edge of the Filchner-Ronneis glacier in the Weddel Sea. Comparison with historical measurements since the 1980s shows that the water masses on the southern continental shelf of the Weddel Sea appear to be relatively stable and still dominated by cold and dense water masses, which protect the ice shelf from the inflow of warmer measurement series under the Filchner-Ronne ice shelf in Antarctica. Such a comparison also shows that the density-driven ocean circulation under the glacier has intensified since 2015, in response to amplified wind-driven sea ice formation in the southwestern Weddel Sea. Another study, Hofstede et al. (2021), presents the results of seismic and radar surveys of the ice and seabed at the Support-Force glacier, which flows into the Filchner-Ronne ice shelf. These rare measurements indicate a complex interaction between the ocean and the outflow of water along the underside of the ice sheet.

Gladstone et al. (2021) describe a flexible new framework, called the Open Source Framework for Ice Sheet – Ocean Coupling (FISOC), which uses a modular approach to linking together various numerical land ice and ocean models.

The use of snow radar to measure snow accumulation over the Nivlisen Ice Shelf in Dronning Maud Land over the past 30 years shows substantial variations in snow volumes, with the least snow accumulation on leeward slopes and the most on windward slopes relative to the prevailing easterly wind direction (Pratap et al., 2021). This pattern is relatively stable between periods with little and heavy snowfall, and the results are useful for quantifying snow accumulation in the region and for the quality-assurance of climate models.

Climate in the past and now

Using marine sediments, Crosta et al. (2021) have reconstructed temperature fluctuations over the last 2,000 years on the surface of the Southern Ocean. The results indicate that there is considerable natural variation in the Southern Ocean, and that this may have played a decisive role in the sea ice in this region in recent decades.

Zampieri et al. (2021) studied the relationship between the complexity of sea ice models and their ability to simulate realistic sea ice properties. They found that a more complex model formulation can lead to a better representation of ocean concentrations and snow thicknesses, while at the same time being less relevant for ice thickness and ice drift.

Payne et al. (2021) compared results from projections of sea level change for the 21st century based on climate model scenarios which indicate a generally warmer climate than the previous generation of climate models (CMIP5). The loss of mass from the Greenland ice sheet is greater according to the results from the new CMIP6 due to increased surface melting. For the Antarctic, the results from CMIP6 and CMIP5 are fairly similar.

Edwards et al. (2020) present estimated sea level rises during the 21st century for the latest emission scenarios used as a basis in the new report from the Intergovernmental Panel on Climate Change (IPCC AR6 WG1). The report supports the view that limiting global warming to 1.5°C will halve the contribution of land ice to sea level rise during the 21st century compared with the scenario based on current emission pledges. However, with risk-averse (pessimistic) assumptions, ice losses in the Antarctic could be five times greater, increasing the land ice contribution to 42 centimetres based on current policies and pledges concerning emission cuts. Ogundare et al. (2021) found several areas where the ocean absorbs CO_2 along the coast of Dronning Maud Land, which is important given the significance of this region as regards the role of the Southern Ocean in global marine CO_2uptake.

Van Liefferinge et al. (2022) used an advanced snow radar to take detailed measurements of snow accumulation in the area around Dome Fuji in East Antarctica. The observations show considerable local variations in snow accumulation linked to small-scale topography, which may be widespread across much of the Antarctic Plateau and is not captured by regional climate models. This is of importance as regards the location of the oldest ice sheet in Antarctica and estimates of the mass balance of the inland ice. A study by Conte et al. (2021) analyses how ocean circulation over time has impacted on sediment deposition along a sector of the continental shelf in the Ross Sea in Antarctica.

CLIMATE ARCHIVE Air bubbles in glacier ice can reveal how much CO_2 was present in the atmosphere thousands of years ago. This ice originates from a depth of 150 metres and is around 2,000 years old. The piece of ice shown in the photograph represents a time span of 10 years. *Photo: Andrea Taurisano / Norwegian Polar Institute*

NUNATAKS Most of Antarctica is covered by ice, but in some places extensive mountain ranges project out of the ice cap. The mountains, known as nunataks, are completely free of vegetation. This gives geologists a unique opportunity to study the processesthat formed the rocks. This picture was taken from Trollkammen, in Jutulsessen, Dronning Maud Land. *Photo: Synnøve Elvevold / Norwegian Polar Institute*

Geology

Engvik et al. (2021) studied a layered magmatic complex in Mühlig-Hofmannfjella, Dronning Maud Land, which consists of the rocks charnockite (olivine- and/or orthopyroxene-bearing granite), dolerite and leucogranite. Charnockite, the dominant rock in the layered complex, is very rich in iron and contains both olivine (Fa94-96) and orthopyroxene (Fs80-84). Radiometric dating and isotope analyses show that the magmatic activity took place around 515 million years ago and that the age of the magma source was approximately 1,100 million years. The formation of the layered complex is the result of magmatic processes followed by metasomatism. The results of this work have provided an insight into a number of crustal processes which took place in a late phase of the formation of the Gondwana landmass, which were characterised by crust thinning, mantle upwelling and high heat flow.

Methods and tools

Matsuoka et al. (2021) present a comprehensive description of the features of "Quantarctica" - a package of geographic data sets covering Antarctica. Ancin-Murguzur et al. (2021) used near-infraredspectroscopy (NIRS) to estimate the isotopic ratio between carbon and nitrogen in samples collected from Antarctic petrel. The results show that the method can accurately predict the results of the measurements, indicating that NIRS can be a time- and cost-effective method for estimating the stable isotopic ratio between carbon and nitrogen and for learning about the nutritional ecology of animals.

Maps and mapping

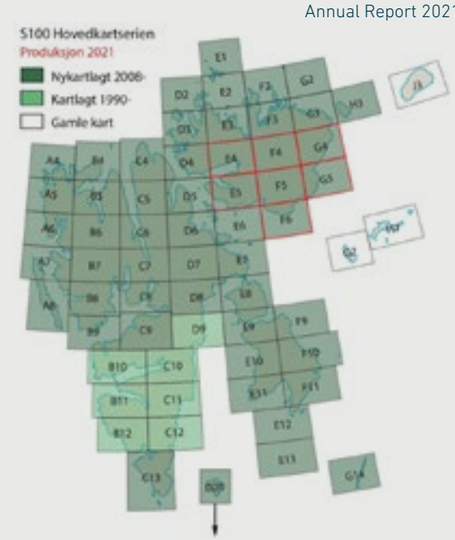
Topographic mapping

The Norwegian Polar Institute's map production in Svalbard is based on digital aerial images after the whole of Svalbard was photographed during the period 2008-2012. This was the first time that Svalbard was photographed using digital sensors. Previously, analogue aerial images were scanned and used in our digital production process. The digital images have given us both a significant improvement in efficiency and greater accuracy. In addition, we now produce digital orthophotographs from these images. Only Kvitøya and Kong Karls Land remain to be mapped before we have digitally mapped the whole of Svalbard. We are also working to re-construct our older digital maps, which were previously based on analogue aerial images dating from the period 1990-94. As regards these maps, only an area in the southern part of Spitsbergen (Van Keulenfjorden to Agardhdalen) remains to be done before we will have modern digital maps, terrain models and orthophotographs covering the whole of Svalbard. Orthophotographs and topographic models are produced on an ongoing basis as part of the map production process and published in the Toposvalbard map service. A new satellite image mosaic (Sentinel) covering the whole of Svalbard was one of the major new developments in Toposvalbard in 2021.

The Norwegian Polar Institute is the naming authority in Svalbard and Antarctica, and the naming committee approved several new place names in 2021.

Within the field of geodesy, we have started a collaboration with the Norwegian Mapping Authority to establish a better vertical datum in Svalbard. Until recently, the current vertical datum has not been defined in the *EPSG Geodetic Parameter Dataset* international register. During the process of entering the data set in the register, it was decided to establish a better vertical datum, as the datum that is currently in use is based on relatively old data which contains some errors and deficiencies.

In the case of Antarctica, we have established a fully digital production process to create topographic maps from satellite images. This was also used for the re-mapping of Jan Mayen. A digital edition of a new 1:50,000 topographic map of Jutulsessen in Dronning Maud Land has been completed. The map will also be published as a printed topographic map and as an information map concerning the operation at Troll. This map has been used as a basis for the Norwegian Polar Institute's new geological map of the area.



SVALBARD MAPS The Norwegian Polar Institute produces both topographic and geological maps of Norway's polar regions and is the main organisation responsible for the topographic mapping of Svalbard and Jan Mayen in the North, as well as Bouvet Island and the Norwegian dependencies in the Antarctic. *Maps: Norwegian Polar Institute*

At Troll, we have established a drone-based production process to rapidly update the detailed maps and terrain model of the area around the station. These are important tools for the planning, operation and maintenance of the station area. In 2021, we published a new version of the GIS system "Quantarctica".

Geological mapping

In 2021, the Institute continued its efforts relating to quality assurance and digital facilitation of the Institute's database for geological maps and associated data. Furthermore, we have completed, published and printed the geological and geomorphological maps of Jutulsessen in Dronning Maud Land at a scale of 1:50,000. We have catalogued geological samples collected during research expeditions to the Arctic and the Antarctic. The rock collection contains almost 3,000 samples and associated information about each of them. In 2021, a strategic roadmap was prepared for the further geological mapping of Dronning Maud Land.

The GeoSvalbard geological display solution at https://geokart.npolar.no/geologi/GeoSvalbard has been continued and maintained.

Data management

The Norwegian Polar Institute is the central data centre for environmental knowledge concerning the polar regions. We make environmental and research data openly available via https://data.npolar.no and https://svalbardkartet.npolar.no. The data centre currently manages 470 sets of data, around half of which are directly available. Data is disseminated through national and international services such as Geonorge, NMDC (Norwegian Marine Data Centre), Nordatanet, SIOS data portal, DataCite and the Antarctic Metadata Directory.

In 2021, the Norwegian Polar Institute contributed to a national study of rights and licensing issues in connection with the sharing of data sets in research. We have also led the work under IASC/SAON's Arctic Data Committee and SCAR's Standing Committee on Antarctic Data Management, which has led to the establishment of new key principles for a coordinated data policy for SCAR, IASC, SAON and other polar research collaborations.

POLAR RECRUITS Pollutant researcher Geir Wing Gabrielsen together with polar recruits Malin Kvaal Bergland (centre) and Øyvor Gjerde on a boat trip in Kongsfjorden in Svalbard. *Photo: Harald Dag Jølle / Norwegian Polar Institute*

Dissemination

Normally, the Norwegian Polar Institute regularly arranges open Friday lectures, a Polar book café and other lectures, but the COVID-19 pandemic once again impacted on our events in 2021. However, this activity picked up again during the autumn.

Nevertheless, some arrangements were held, including during Arendal Week, when we arranged the debate entitled "The Arctic is changing at record speed. Is humanity prepared?". During this event, we highlighted the then very recent IPCC report and the Institute's research concerning climate change, with a particular emphasis on the Arctic Ocean.

The Leader of the Labour Party, Jonas Gahr Støre and Mayor Gunnar Wilhelmsen visited FF Kronprins Haakon in June while the ship was docked in Tromsø. We also arranged a press conference on board the transport vessel Silver Arctic to mark the role of the ship in transporting scientists and supplies to Antarctica during the 2021 summer season. As the ship set sail and headed south towards the ice margin, we arranged a celebration on the quay in Tromsø.

In August, all owner institutions, i.e. the Institute of Marine Research, UiT The Arctic University of Norway and the Norwegian Polar Institute, took part in events on board FF Kronprins Haakon to mark the official change of ownership.

The development of content and features on the website npolar.no continued in 2021. The most read news article on the website during the year was "The talented research scientist reduced to a femme fatale", which was also published on forskning.no, where it was voted best article of the year in competition with over 1,000 other articles. In addition to the website, the Norwegian Polar Institute uses the platforms Facebook, Instagram, Twitter and YouTube to reach a wider digital audience. In 2021, we rounded off the “polar recruits” climate project, where we followed two young people as they learned about climate change, pollutants and polar history. The recruits made several

GLACIER RESCUE Glaciologists practising crevasse rescue near Ny-Ålesund before the start of this year's fieldwork. Photo: Stein Tronstad / Norwegian Polar Institute

Logistics and infrastructure

trips to Svalbard, with the main excursion being the "Plastic Cruise" in the summer of 2021.

Many Norwegian and foreign media used the Norwegian Polar Institute as a source or referred to us in their articles, including NRK, VG, Klassekampen, Nordlys, Svalbardposten, CNN and the BBC.

In March, we opened an exhibition at Svalbard Museum about Svalbard's changing nature in partnership with COAT.

In 2020, the Norwegian Polar Institute started a pilot project specifically aimed at young people who we called the "Polar Recruits". Theaim was to create engagement amongst young people regarding research. The main prize was the chance for two students to join the plastic cruise on FF Kronprins Haakon. The COVID-19 pandemic and maintenance work on the ship delayed the first cruise until 2021.

The Norwegian Polar Institute's book collection contains more than 15,000 volumes, mostly specialised literature on the polar regions. Work is under way to build up a multidisciplinary database of Norwegian literature on the Antarctic, which currently contains more than 2,000 publications. The photographic collection consists of around 130,000 photographs and dates all the way back to 1872. The historical collection includes approximately 60,000 images. Around 100,000 images have been digitised, most of which are searchable for the general public via the image database on the website npolar.no.

Support

Despite the COVID-19 pandemic, the 2021 season saw a high level of activity both in the field and on cruises. Courses were run as normal, with both internal and external delegates. The replacement of the field cabin in Revdalen on Bjørnøya began. The traditional deployment cruise to Svalbard was renamed “Statstokt” (The State Cruise) and the Norwegian Coastal Administration once again provided KV Svalbard for the 2021 cruise.

FF Kronprins Haakon

The planned cruises on the research vessel Kronprins Haakon were carried out in 2021, with no major technical challenges being encountered. Two workshop periods were conducted, during which a number of warranty works were carried out. Ownership of the vessel was officially transferred to the Norwegian Polar Institute through the issuing of a new certificate of nationality on 7 July 2021.

Towards the end of the year, it was decided that the research vessel would ensure the establishment of a new unloading point for our supply vessel to Troll. FF Kronprins Haakon began its long voyage south on 18 November 2021. The vessel’s itinerary included a change of personnel at Cape Verde and the bunkering of fuel in Cape Town. A new unloading point was established around the New Year.

Ny-Ålesund Research Station - Sverdrup and Zeppelin Observatory

The Norwegian Polar Institute operates Sverdrup and the Zeppelin Observatory as part of Ny-Ålesund Research Station, and runs measurement series for dozens of national and international institutions from there. Sverdrup is the host for research scientists from Norwegian institutions, as well as for research scientists from foreign institutions which do not have their own long-term programmes in the region. During 2021, a total of 3,298 research days were registered at Sverdrup. Of these, research scientists from the Norwegian Polar Institute accounted for 934, equivalent to 28%.

Troll

Like the previous season, the start of the 2021-22 season was affected by the pandemic. The infection control protocol was drawn up in accordance with guidelines issued by COMNAP and entailed, amongst other things, 14 days of quarantine and isolation in hotels before entering Antarctica, regular testing and social distancing requirements. There were no known cases of COVID-19 at Troll Research Station in 2021.

The Norwegian Troll Research Station supports Norway's national policy and interests in Antarctica, both in terms of the goal of protecting Norway's interests as a claimant country, and in connection with the nation's role in the cooperation under the Antarctic Treaty System. Active interest in research is a fundamental precondition for participation in this collaboration.

Troll's technical condition is now such that it is in need of upgrading. First and foremost, this will be necessary to ensure proper operation and ensure the safety of the personnel who will overwinter there, as well as to safeguard the tasks associated with the station. We must also facilitate further development of Troll as a relevant platform for research. The ambition of green and sustainable solutions linked to Troll will also require new technical solutions to be phased in.

In 2020, the Ministry of Climate and Environment commissioned the Norwegian Directorate of Public Construction and Property (Statsbygg) to carry out a choice of concept study for future upgrades to the Troll station. Throughout the project period, the Norwegian Polar Institute has worked closely with Statsbygg and provided information as and when necessary. In 2021, we completed the problem statement, needs analysis, strategic objectives and framework conditions for the choice of concept.

One of two emergency generators was also installed during 2021. The power station's UPS system was also replaced, and the district heating system was expanded to cover more buildings, which will help to reduce power consumption. Minor upgrades and maintenance were also carried out on the main station.

Troll Station has a six-person overwintering team, which operates the station from early March to early November. During the southern summer, the number of persons present at the station often increases to 30-40 due to visiting scientists, maintenance and logistical tasks.

During the southern summer of 2020/21, a total of six out-and-back transport traverses were carried out from Troll to Sledneset. These traverses take an average of five days. In February, improvements were made to the hinge zone involving diversion of the route to create a safer route to the coast. The hinge zone is an area where there are large cracks in the ice which form as the ice shelf flows over the transition from land to sea. The task of the hinge zone team is to establish a safe route by mapping and inspecting cracks, and then filling them with snow.

In December, a new location was established for unloading the supply vessel which is situated west of the old unloading site, after the previous site became inaccessible after it calved into the sea. In recent years, the Norwegian Polar Institute has monitored the situation and inspected a number of possible alternative unloading sites in advance. The depot for the intermediate storage of containers was established at a safe distance on the inland side of the cracks.

During 2021, a formal cooperation was established with the Norwegian Meteorological Institute for weather reports from Troll. The weather is reported at 06.00, 12.00 and 18.00, 365 days a year.

PORTAL TO ANTARCTICA Troll Airfield is located on the blue ice at Troll Station. The airstrip is operational during the Antarctic summer season and is used for flights to/from Antarctica and within the continent.
Photo: Sven Lidström / Norwegian Polar Institute

Troll Airfield

The Norwegian Polar Institute conducted two intercontinental flights linked to the activities being carried out at Troll in 2021. In February, the route from Keflavik - Cape Town - Troll - Cape Town - Oslo was operated without any overnight stays due to the pandemic and high infection rates in Cape Town. The first and only flight to Troll during the 2021-22 season took place on 15 November from Gardermoen via Cape Town. In 2021, a total of 30 passengers were brought in and 20 passengers taken out, and 7.5 tonnes of freight was transported via Troll Airfield.

During the year, nine flights were operated by helicopter and aircraft within the continent, from other national programmes via Troll Airfield

Maintenance and upgrading of Troll Airfield continued during 2021.

Vessel logistics

Every year, the logistics cruise keeps the Troll Station supplied with provisions, fuel, consumables and building materials, etc. Arrival at Sledneset at the ice margin during the 2020-21 summer season took place on 31 December 2020, and the vessel departed from Sledneset again on 4 January 2021. A total of 714 tonnes and 51 containers were transported in, while 9 tonnes and 3 containers were transported out. Unloading of the vessel Malik Arctica took 10 days in January, including transport from Troll-Sledneset-Troll.

We carried out a tender process for a new supply vessel for Antarctica, which led to a new framework agreement being signed on 26 May with the Norwegian shipping company Silver Line AS concerning their vessel Silver Arctic. The vessel set sail with supplies for Troll from Tromsø on 23 November 2021.

Publications

The Norwegian Polar Institute's website **npolar.no** provides an overview of publications by the Institute. In **Cristin**, the national archive, the publications are available in full dating right back to the oldest publication, which dates from 1922.

Brief reports

In the brief report series, academic/scientific works are published in a limited format.
Five brief reports were published during 2021.

#55: Spreading of southern vole and parasites in Svalbard: Final report to the Svalbard Environmental Protection Fund / by Eva Fuglei; Dominique Fauteux; Audun Trail; Nigel G. Yoccoz; Stein Tore Pedersen; Rolf Anker Ims

#56: Panel-based assessment of ecosystem condition (PAEC) as a knowledge platform for ecosystem-based management of Norwegian Arctic tundra / by Åshild Ønvik Pedersen; Per Arneberg; Eva Fuglei; Jane Uhd Jepsen; Jesper Mosbacher; Ingrid Marie Garfelt Paulsen; Virve Ravolainen; Nigel G. Yoccoz; Ellen Øseth; Rolf A. Ims

#57: Svalbard char (Salvelinus alpinus): compilation of management-relevant knowledge / by Hanne Johnsen; Henrikke Rokkan Iversen; Therese Sigurdsen

#58: Seabirds in the marine areas around Jan Mayen and along the Mid-Atlantic Ridge: basic report in connection with the opening process for exploration and extraction of seabed minerals on the Norwegian continental shelf / by Hallvard Strøm; Benjamin Merkel; Arnaud Tarroux; Erlend Lorentzen

#59: Waders in Kongsfjorden, Svalbard / by Hilde Dørum; Geir Wing Gabrielsen

Report series

The report series contains scientific and environmental reports. One report was published in 2021:

#153: Norwegian Arctic tundra: a panel-based assessment of ecosystem condition / by Åshild Ønvik Pedersen

Polar Research

Polar Research is the Norwegian Polar Institute's international peer-reviewed journal and was the first publication aimed at the polar regions which gave readers open access. During 2021, almost 100,000 readers visited the website: https://polarresearch.net/index.php/polar

Data sets

Scientific and other data sets are published at data.npolar.no, either as downloads or via application programming interfaces (API). All published data may be freely reused under a CC-BY licence, with appropriate crediting. A total of 28 new data sets was published in 2021. All published data sets have persistent and unique identifiers (DOI) for easy citation.

Maps

Maps produced by the Norwegian Polar Institute include maps from Svalbard, Jan Mayen, Dronning Maud Land, Peter I Øy and Bouvetøya. The main map series for Svalbard is in the scale of 1: 100,000. In 2021, seven topographic maps were published./

E4 – Wahlenbergfjorden

E5 – Gustav Adolf Land

F4 – Austfonna

F5 – Vibebukta

F6 – Bråsvellbreen

G4 – Isispynten

G5 – Isdomen

Ortophotographs of Wedel Jarlsberg Land and Torell Land (Svalbard) were produced and published in 2021.

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ABBREVIATIONS

AMAP	Arctic Monitoring and Assessment Programme (Arctic Council)
ATCM	Antarcitc Treaty Consultative Meeting
ArcOP	Arctic Ocean Paleoceanography
ARICE	Arctic Research Icebreaker Consortium (EU-funded initiative)
ARK	ARK - Arctic marine mammals in a time of climate change: a Kongsfjorden Case Study (Research Council of Norway)
ASPA	Antarctic Specially Protected Area
AWI	Alfred Wegener Institute (Germany)
BEOIC	Beyond EPICA-Oldest Ice
BEPSII	Biogeochemical Exchange Processes at the Sea-Ice Interfaces
CAFF	Conservation of Arctic Flora and Fauna (Arctic Council)
CBD	Convention on Biological Diversity
CBird	Circumpolar Seabird Expert Group
CCAMLR	Convention for the Conservation of Antarctic Marine Living Resources
CCICED	China Council for International Cooperation on Environment and Development
CEMP	Circumpolar Biodiversity Monitoring Program (CCAMLR)
CEP	The Committee for Environmental Protection (to the Antarctic Treaty)
CM51-07	Conservation Measure 51-07
CMIP5, CMIP6	Coupled Model Intercomparison Project 5 (CMIP5) & Project 6 (CMIP6)
COAT	Climate-Ecological Observatory for Arctic Tundra
COMNAP	Council of Managers of National Antarctic Programs
EBSA	Ecologically or Biologically Significant Marine Areas
FACE-IT	The future of Arctic coastal ecosystems - Identifying transitions in fjord systems and adjacent coastal areas (EU)
FVCOM	Finite Volume Community Ocean Model
GOA-ON	Global Ocean Acidification Network
IASC/SAON	International Arctic Science Committee / Sustaining Arctic Observing Networks
ICES	International Council for the Exploration of the Sea
IODP	Integrated Ocean Drilling Program
IPCC	The Intergovernmental Panel on Climate Change
MMBI	Murmansk Institute of Marine Biology
MOSAiC	Multidisciplinary drifting Observatory for the Study of Arctic Climate
MOSJ	Environmental monitoring of Svalbard and Jan Mayen
MPA	Marine Protected Area
NAMMCO	North Atlantic Marine Mammal Commission
NILU	Norwegian Institute for Air Research
NIVA	Norwegian Institute for Water Research
NPI	Norwegian Polar Institute
OA-DREAM	Ocean Acidification - Drivers and Effects on Arctic Marine organisms and ecosystems
OECM	Other Effective Area-based Conservation Measures
PAME	Protection of the Arctic Marine Environment (Arctic Council)
RINGS	RINGS Action Group (ice sheet margin) (SCAR)
RIS	Research in Svalbard
SCAR	Scientific Committee on Antarctic Research
SESS	State of Environmental Science in Svalbard
SIOS	Svalbard Integrated Observing System
SIWHA	Sea Ice and Westerly winds during the Holocene in coastal Antarctica
SO-CHIC	Southern Ocean Carbon and Heat Impact on Climate
SOPHY-CO2	Southern Ocean phytoplankton community CO2
SUFIANT	Sustainable and predictable future for fisheries in Antarctica
SUSTAIN	Sustainable management of renewable resources in a changing environment: an integrated approach across ecosystems.
SVO	Particularly valuable and vulnerable areas
TONe	Troll Observing Network
WGIBAR	Working Group on the Integrated Assessments of the Barents Sea
WMS	Web Map Service
WSMPA	Weddell Sea Marine Protected Area

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