the Nansen LEGACY

Annual report
2019

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Statement from the Board

The Nansen Legacy project has completed its second year, and the Board is pleased to see that this innovative, new research project develops according to plan. The project addresses the changes and responses in the eco- and climate system in the northern Barents Sea and adjacent Arctic Basin, and it will lay the foundation for a knowledge-based sustainable management of this region. The board is pleased to note that the improved understanding of the importance of the ice edge and the seasonal ice zone for the functioning of the Barents Sea ecosystem provided by the project already feeds into ongoing political discussions in Norway.

The unique aspect of The Nansen Legacy project is its earth system science perspective, involving interdisciplinary expertise, logistics, collaboration and integration across institutions that goes well beyond traditional science cooperation. With ten institutions and a scientific team of 140 scientists, and with the ambition to train a new generation of polar researchers through the involvement of 50 PhD students and postdocs, The Nansen Legacy project develops a new approach to research as a strategic tool to address these complex research questions.

The new ice breaking research vessel *Kronprins Haakon* has proved to be an excellent platform for Arctic research, and a unique platform for fostering collaborations between the participants from different disciplines and institutions.

The board is happy to see that the regional knowledge established is contributing to the larger international effort of gaining a more holistic understanding of how the Arctic Ocean functions and responds to ongoing climate change. The size and structure of the project has made the Nansen Legacy project internationally visible, and has facilitated more extensive collaborations with international research programs and organisations. The Board is happy to see that the project maintains a close dialogue with stakeholders through scenario building workshops, side events communicating the new knowledge, and by contributing to international synthesis processes.

The interdisciplinary focus and work show good progress. The Board notes the enthusiasm of the early-career scientists for working in interdisciplinary teams and participating in the dedicated PhD courses provided by the project, which expand the perspectives and context of their own research and the Arctic system.

The Board commends the project leadership and the management team for their excellent work on securing a flying start for this exiting project and look forward to exciting new results and achievements.

The Nansen Legacy breaks the ice

From left to right: PI Marit Reigstad, co-PI's Tor Eldevik and Sebastian Gerland.
Photo: Magne Velle

Last year, the Nansen Legacy set sail. This year we move forward with our ambitions for Arctic research. The over 50 Nansen Legacy early career scientists are the most direct manifestation of how we are progressing with respect to deepening our Arctic knowledge and inter-disciplinary integration. These emerging experts already show the ability to see the broader context, to see how other disciplines complement their work, and to provide new perspectives. As the PIs of the Nansen Legacy project, we find this very encouraging: The new generation takes lead in breaking the ice between disciplines, and is paving the way for a more holistic understanding of the Arctic marine environment through the looking glass of the Barents Sea.

The Arctic Ocean is an excellent field to develop a more extended perspective in natural sciences. The need to link ongoing climate change to responses in the physical environment and the ecosystem require collaborations across disciplines and perspectives across both time and spatial scales. One important delivery from the Nansen Legacy project is improved weather and sea ice forecasts. In 2019, important effects of sea ice leads and snow on ice on weather forecasting systems were published and implemented into weather forecasting models. Exploration of metrics to verify short term sea-ice forecasts and end-user needs has improved the quality of these matrices. On the long-term end, projections of future sea-ice conditions in the Barents Sea and important drivers suggest it is still possible to have ten-year periods with increasing ice cover due to changes in the Atlantic flow, despite an overall trend of diminishing sea ice.

Collection of new data to establish the knowledge base for this region is another important delivery. A series of seasonal joint cruises was initiated in August 2019 to investigate the physical environment, the chemical and biogeochemical characteristics, and the many components of the ecosystem along the Nansen Legacy climate gradient through the Barents Sea. The second seasonal cruise took place in December 2019, and managed a successful sampling program despite darkness, low temperatures, and strong winds. The observations supported the growing understanding of high biological activity also during the Polar night in the Arctic.

Moorings with a wide range of sensors deployed in 2018 were successfully retrieved in November 2019 despite darkness, sea ice and rough seas, thanks to the competence and efforts by the excellent crew and scientists on *RV Kronprins Haakon*. The new research vessel proved its capacity and suitability as a research platform. The re-covered sensors provide important data to quantify and understand the impact of Atlantic Water on the Barents Sea climate. The cruise was a joint expedition with collaborative projects, and illustrates the valuable synergy of collaborations also across research projects.

The Nansen Legacy project has also been actively interacting with stakeholders both within our reference group and outside. A workshop developing scenarios for the Barents Sea future raised valuable discussions and perspectives, and identified major uncertainties of geopolitical as well as climatic nature. Contributions to international synthesis work like IPCC and AMAP assessments are also a prioritized task.

The successful development of the project that we see after the second project year results from a true collaborative effort. Breaking the ice and passing the open leads between institutions and disciplines is not a quick and easy job. A dedicated effort is invested to plan and conduct all the field campaigns and to coordinate work within and across institutions and disciplines. The logistic team is invaluable in handling challenging field logistics from Longyearbyen. The students´ enthusiasm and energy boost the project. We would like to thank everyone working in the project for bringing enthusiasm and competence to understand the changing marine system in the north. It is promising for the coming years of the project, and our ambitions to break ice and build a holistic understanding for the climate and ecosystem sciences.

Vision and objectives
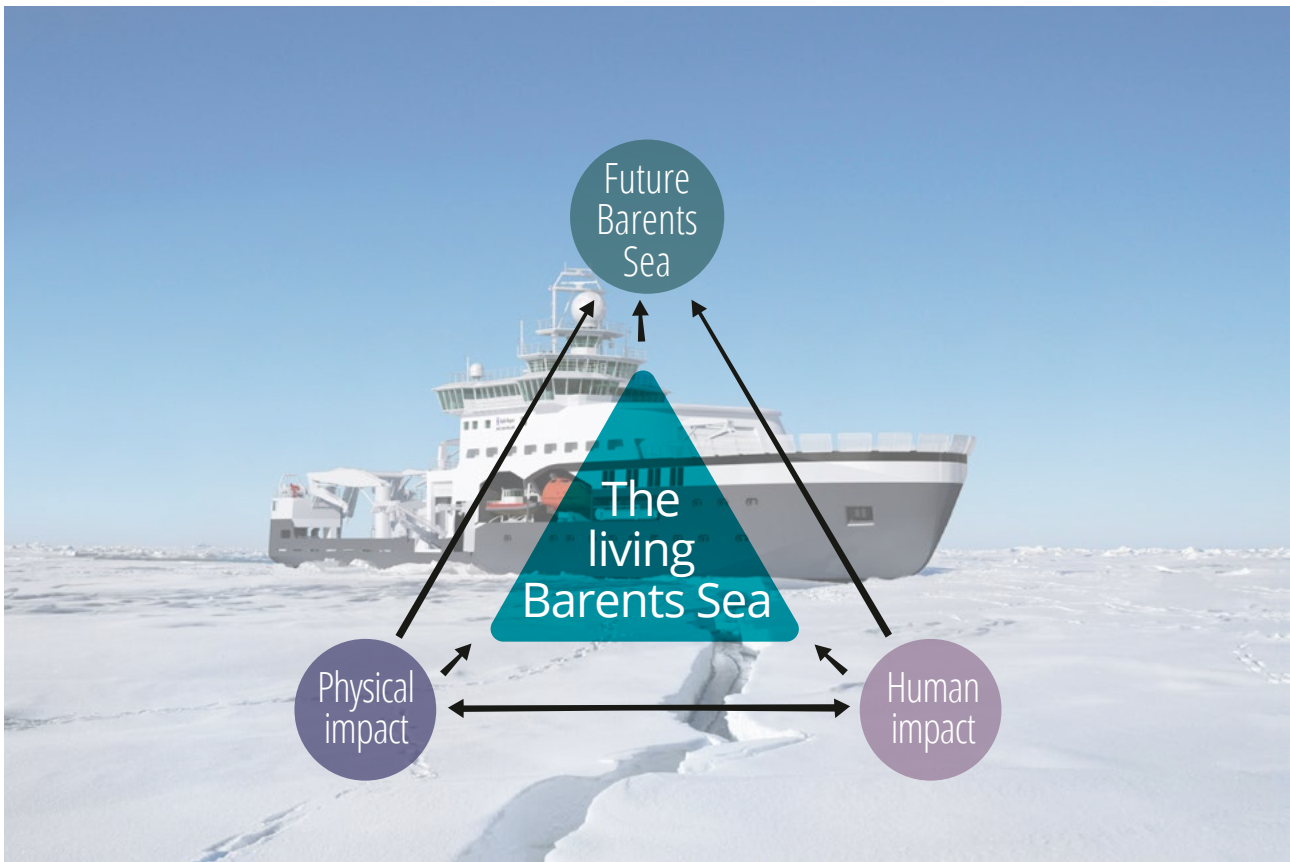
The four research foci of the Nansen Legacy. Physical and human impacts on the living Barents Sea will determine the state of the future Barents Sea.
Illustration: Tor Eldevik, Rudi Caeyers

The Nansen Legacy is a novel and holistic Arctic research project. It provides integrated scientific knowledge for sustainable management of the marine environment and resources of the Barents Sea and adjacent Arctic Basin through the 21th century. The Nansen Legacy has the following objectives:

1 Improve the scientific basis for sustainable management of natural resources beyond the present ice edge

2 Characterize the main human impacts, physical drivers, and intrinsic operations of the changing Barents Sea ecosystems in the past, present and future

3 Explore and exploit the prognostic mechanisms governing weather, climate and ecosystem, including predictive capabilities and constraining uncertainties

4 Optimize the use of emerging technologies, logistic capabilities, research recruitment and stakeholder interaction to explore and manage the emerging Arctic Ocean

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Packing an ice core for investigation of its microbial inhabitants back in the lab.
Photo: Christian Morel / christianmorel.net

2019 in brief

Nansen Legacy **workshops** on how technology can be used in oceanographic studies, as well as the oceanographic data retrieved from the cruises.
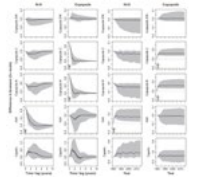

Start of Nansen Legacy **webinar series on transferable skills**, especially aiming at the many early career scientists in the project

The Nansen Legacy does not want to be an "island on its own", but seeks to share knowledge with a broad range of societal stakeholders. The Nansen Legacy therefore invited its **reference group** for a **dialogue meeting**.
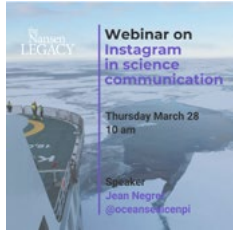

Nansen Legacy **stakeholder workshop** on the future Barents Sea, risks, mitigation and adaptation options.

Start of the **seasonal investigation** with a 22 day long **cruise** in August to the northern Barents Sea.

Second Nansen Legacy **workshop** on best practices for ecological model evaluation.

SPRING

Test of technology and sensors during a test cruise in Norwegian coastal waters, to identify an optimum solution and strategy for deployment of underwater robots in the Barents Sea.

Nansen Legacy **workshops** on experimental and ecotoxicological work.

SUMMER

Start of Nansen Legacy **science webinar series**, which will bring together scientists from different fields and disciplines to discuss different overarching scientific topics.

International collaboration is important for the project, and Nansen Legacy contributed to the annual meeting of the Nansen Legacy's UK collaborating projects.
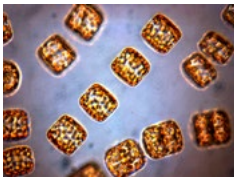
Hundred and fifty Nansen Legacy scientists met for the project's **annual meeting** in Oslo, discussing data, planning forthcoming cruises, and presenting first results.

Joint Nansen Legacy, ATWAIN, SIOS-Infra-Nor **mooring service cruise** successfully recovered and redeplyed all Nansen Legacy oceanographic moorings in the Barents Sea.
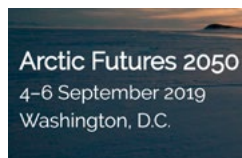

Second Nansen Legacy **workshop** on protist taxonomy.

Sampling the **Russian** part of the Barents Sea during a **cruise** on RV *Dalnie Zelentsy.*

Nansen Legacy scientists join the **international** ice drift campaign.

AUTUMN

WINTER

Participation in **panel debates** on the societal impact of climatic changes in the Arctic under the conference Arctic Futures 2050.

Arctic Futures 2050
4–6 September 2019
Washington, D.C.

Continutation of the **seasonal investigation** with a **cruise** to the northern Barents Sea during November and December.

The project was well represented during the **National Research Days** with stands, school activities and a popular science evening at the Literature House in Oslo.

Nansen Legacy contributed to the **IPCC special report** on the Ocean and Cryosphere in a changing climate, which was published Sep 25.

Nansen Legacy early career scientists met for to a two day **Recruit Forum** in Oslo, giving them time to get know each other and learn about each other's research.

Photo: Leif Christian Stige

Reduction in Arctic sea ice cover affects marine food webs through a multitude of direct and indirect effects

Humans imitate the physical world in many ways - from paintings over railroad models to mathematical representations of processes surrounding us. Ecological models are such mathematical representations of either entire ecosystems or more specific species interactions.

Ecological models can be used to understand, predict or give forecast on the ecological system. There is no model that can do everything at once, so in the Nansen Legacy different groups of researchers work with different models. This way they can compare outputs and construct a more holistic picture. One type of ecological models that are used in the Nansen Legacy are statistical state-space multispecies models. Here, the ecosystem is simplified to a few important players and processes, and the purpose is to quantify roles of processes that are potentially important for population and ecosystem dynamics, and hence improve our understanding of the ecosystem.

Investigating 35 years of data
Using a state-space multispecies model and observations of the year-to-year variations in the biomasses of the various fish species and zooplankton groups over the last 35 years, Nansen Legacy scientists analyzed effects of variability in sea ice cover on the pelagic food web in the central and northern Barents Sea. Sea ice cover can affect species either directly or indirectly. Direct impacts can emanate from changes in the environment, such as increasing water temperatures. Such environmental changes can either lead to a positive or negative development in the abundance of a species. Indirect impacts on a species are through effects on the species' predators, competitors or prey.

Winner and looser of sea ice decline
The model study showed a complex interaction of direct and indirect effects of sea ice cover variability on the marine food web in the Barents Sea. Increasing water temperatures had a direct effect on the dominant krill species by a northward expansion of their habitat. The positive direct effect of increased water temperature on

krill was however counteracted indirectly as the krill's predator, capelin, also was positively directly affected by increased temperatures, and likewise increased in numbers. Whether krill biomass will increase or decrease in a warmer climate therefore depends on what happens to their main predator, the capelin.

For the predominantly arctic copepods in the region, it is simpler. The direct effect of warming is shown to be negative. In addition, they are likely to face increased predation in a warmer climate. For these copepods, both the short-term and the longer-term effects of warming are therefore negative.

"This shows the importance of assessing potential feedback mechanisms between higher and lower trophic levels when studying climate effects on marine ecosystems."

Leif Christian Stige, UiO

Reference:
Stige, L.C., Eriksen, E., Dalpadado, P., and Ono, K. (2019). Direct and indirect effects of sea ice cover on major zooplankton groups and planktivorous fishes in the Barents Sea. ICES J. Mar. Sci. doi:10.1093/icesjms/fsz063

Photo: Rudi Caeyers

The elusive sea ice edge

Last winter an almost forgotten sight presented itself to all those venturing the Barents Sea: sea ice as far south as Bjørnøya, equaling a sea ice extent not seen since the eighties and nineties. Are you wondering how this is possible in times of global warming and a diminishing Arctic ice cap?

The answer lies in the strength of the North Atlantic current that transports large amounts of warm water from the south into the Barents Sea. The heat from these water masses melts sea ice drifting into the Barents Sea from the north, and prohibits local ice formation. Hence, years of strong Atlantic water inflow result in a largely ice-free Barents Sea, and vice versa. In a recent study, Nansen Legacy researcher Marius Årthun and colleagues from UiB studied in detail how natural variations in the water temperature and the strength of the North Atlantic current affect the size of the future ice cover in the Barents Sea. The study shows that in a warming world, years of sea ice expanses as seen this winter are becoming increasingly unlikely, although not entirely impossible. Importantly, it is possible to predict these natural variations in sea ice extent based on the strength of the Atlantic water inflow. Using this method, Årthun and colleagues were already in 2015 able to foresee sea ice pilling up in the Barents Sea this winter. The reason: A weaker and colder Atlantic current in recent years.

Seasonal forecasts of sea ice edge position

The variability in sea ice extent affects human activities. Short and long-term forecasting of the ice edge position is therefore required for safe operations in the Arctic. Seasonal sea ice forecasting is still in its infancy, but different algorithms already produce seasonal sea ice edge forecasts. Good methods to verify and improve the forecasting skills are still needed. Forecast evaluation requires accurate long-term satellite observations of various sea ice characteristics, such as ice concentration, thickness and ice edge position. In a recent study, Cyril Palerme and Nansen Legacy researchers at MET compared historical 25-member ensemble ice edge forecast to satellite ice observations. The comparison showed that different methods for verification for probabilities of meeting ice covered waters have different strengths and weaknesses, and choice of method will depend on the purpose of the seasonal forecast.

Quality of sea ice edge forecasts for navigation

In addition to seasonal forecast, ship navigation in the Arctic requires shorter-term ice forecasts of high quality. For this purpose, there are many monitoring and forecast products available. Information on the expected accuracy of data or model results from these are traditionally available as a set of metrics that comes with the products. However, when comparing ice edge results from different products, some factors - such as large open water areas within the ice or local freezing along continents - can have a large impact on the quality assessment of the forecasts. To address this, Nansen Legacy researchers Arne Melsom and colleagues at MET examined a large number of metrics used, and concluded with a recommended best practice for the validation of sea ice edge forecasts.

"Our results show that in the future it is still possible to have ten-year periods with increasing ice cover due to changes in the Atlantic flow."

Marius Årthun, UiB

References:
Årthun, M., **Eldevik, T.** and **Smedsrud, L.H.** (2019). The role of Atlantic heat transport in future Arctic winter sea ice loss. *Journal of Climate,* 32:3327-3341. doi: 10.1175/JCLI-D-18-0750.1
Palerme, C., **Müller, M.** and **Melsom, A.** (2019). An intercomparison of verification scores for evaluating the sea ice edge position in seasonal forecasts. Geophysical Research Letters, 46, 4757-4763. doi: 10.1029/2019GL082482
Melsom, A., Palerme, C. and **Müller, M.** (2019). Validation metrics for ice edge position forecasts. *Ocean Science,* 15, 615-630. doi: 10.51947os-15-615-2019

Mapping Nansen Legacy knowledge

Sea ice decline does not only take place during summer, but increasingly also during winter[4]. The Barents Sea and area north of Svalbard are hotspots of winter sea ice loss[4, 5], facilitated through increased ocean heat transport by warm Atlantic Water[4, 5, 6]. Ocean heat transport is therefore a good predictor of winter sea ice variability, although the relation will weaken in the Barents Sea as the ice retreats further polewards[6]. However, short periods of increasing winter sea ice extent in the Barents Sea and adjacent waters are likely to occur also in the future[6].

Warm and salty Atlantic Water that enters the Arctic Ocean through the Barents Sea and north of Svalbard dominates the oceanic heat transport to the Arctic Ocean[1]. This heat transport varies on different time scales, linked to changes in the wind systems in the Nordic Seas[1] and atmosphere-ocean heat exchange upstream[1, 2]. Significant local heat loss can be caused by ocean mixing due to local winds and tides[2]. Overall, the ocean heat transport and the Atlantic Water temperature have increased in recent decades[1]. These changes are especially large at the Barents Sea entrance where the water has warmed about 1°C[1]. In the Fram Strait, increased water temperatures influence the current direction and promote increased inflow into the Arctic Ocean north of Svalbard[3].

Photo: Rudi Caeyers

Sea ice leads and snow cover over ice are important for accurate weather prediction[7, 8].

Representing ice leads and snow cover over sea ice in weather and climate models has potential for improving near-surface temperature and wind forecasts[7, 8]. Effects could be traced up to areas 500–1000 kilometres away from the ice edge[7].

Physical drivers affect the food web structure in the Barents Sea[9, 10].

Reduced sea ice cover, for example, favors krill and capelin, while disfavoring copepods and amphipods[9]. Hence, ice cover indirectly shapes the Barents Sea food web through changes in top-down and bottom-up forcings[9]. Similarly, the size of the cod stock co-varies with the water temperature in the Barents Sea[10]. This allows predictions of the cod stock size for the coming 7 years based on water temperature forecasts[10]. .

Rendering a more accurate representation of the ocean and the processes therein, requires underwater robots that continuously adapt their sampling strategy to local features[11, 12, 13].

First studies have demonstrated how data from such robots can be combined with data from model forecasts, satellites, ocean buoys, and ships, enabling augmentation across platforms and scales[11, 12], resolving upper water-column interactions with improved coverage and accuracy[11, 12, 13]. .
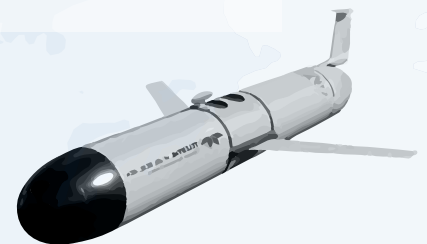
References: 1: Muilwijk et al. 2018, 2: Renner et al. 2018, 3: Crews et al. 2019, 4: Onarheim et al. 2018, 5: Renner et al. 2018; 6: Årthun et al. 2019, 7: Batrak & Müller 2018, 8: Batrak & Müller 2019, 9: Stige et al. 2019, 10: Årthun et al. 2018, 11: Fossum et al. 2018, 12: Fossum et al. 2019, 13: Fragoso et al. 2019

Nansen Legacy cruises

2019

Technology Test Cruise
RV Kristine Bonnevie
Sulafjord & Storfjord
May 25 – May 31

Mooring Service Cruise
RV Kronprins Haakon
Barents Sea
Nov 12 – Nov 27

Seasonal Cruise Q3
RV Kronprins Haakon
Barents Sea transect
Aug 5 – Aug 27

Seasonal Cruise Q4
RV Kronprins Haakon
Barents Sea transect
Nov 28 – Dec 17

2018

Ocean Mixing Process Study
RV Kristine Bonnevie
North of Svalbard
Jun 27 – Jul 10

Physical Process Cruise
RV Kronprins Haakon
North of Svalbard
Sep 12 – Sep 24

Joint Cruise 1/2
RV Kronprins Haakon
Barents Sea transect
Aug 6 – Aug 23

Paleo Cruise
RV Kronprins Haakon
Barents Sea
Sep 26 – Oct 19

Sampling in Russian waters

In mid-October 2019, Akvaplan-niva researcher Vladimir Savinov joined a Russian research cruise on RV *Dalnie Zelentsy* for the Nansen Legacy. Savinov sampled sediments, zooplankton, fish and seawater for the project. This allowed valuable complementary spatial coverage of the northeastern Barents Sea, broadening the regional perspective of questions raised by the Nansen Legacy.

Russian researchers have been sampling the eastern Barents Sea for a hundred years, and their knowledge of the system is extensive. Collaboration with the Murmansk Marine Biological Laboratory through this cruise is therefore highly valuable in reaching the project goals of improved understanding of the changing communities in the northern Barents Sea.

"Getting access to samples from the eastern side of the Barents Sea enables us to fully investigate the sub-populations of fish in this region."

Sissel Jentoft, UiO

Photo: Angelika Renner

Working in the dark

Total darkness, plenty of ice, storms, and temperatures down to -24˚C.
What does the Nansen Legacy do? Head out at sea.

During the Polar night darkness, the Nansen Legacy headed out for two very different research cruises. One was deliberately planned during the year's darkest period in December, while the other cruise involuntarily had to be conducted during November. Deliberately or not, both cruises turned out to be successful.

Moorings up and down
Ship time on *RV Kronprins Haakon* is attractive, and not all wishes can be fulfilled. The cruise for servicing oceanographic moorings could therefore not be conducted in September as intended but was instead scheduled for November. Oceanographic moorings consist of hundreds of meters of wires, huge anchors, they are very heavy, and filled with expensive measuring instruments. More than that, retrieving oceanographic moorings from the ocean is easier when one has ice-free waters, calm conditions and good sight. None of these are likely as late in the season as November. However, despite much ice, wind and darkness, *RV Kronprins Haakon* and the skilled crew and researchers onboard managed to recover 14 oceanographic moorings, deploy 15, take 121 CTD profiles, and deploy one glider. Earlier attempts with non-ice breakers had struggled with the heavy ice conditions in 2019, and had given up on recovering their moorings. The November cruise therefore became a double success – not only did the cruise recover its own moorings but managed to recover those of collaborating projects from the UK, Poland and the INTAROS project.

Joint forces
The mooring cruise in November was also a collaborative success – being shared by three research projects – the Nansen Legacy, the Fram Centre project A-TWAIN and SIOS-InfraNor. They all use oceanographic moorings in the region of the northern Barents Sea and north of Svalbard to understand how the inflow of warm Atlantic Water shapes the physical environment of that region. In order to monitor water masses and currents in the Barents Sea, the Nansen Legacy moorings with instruments were deployed on four strategic locations in 2018. These areas have deeper connection either to the Atlantic influenced part of the south and west, or to the warm current that follows topography on the northern side of the Barents Sea. Providing data from the northern Barents Sea shelf region, the Nansen Legacy complement the A-TWAIN and SIOS-InfraNor moorings covering the inflow of warm Atlantic Water north of Svalbard.

"The Nansen Legacy moorings complement other oceanographic moorings in the region. They help us understand seasonal variations in water temperature and water exchanges between regions."

Arild Sundfjord, NPI

One year in the Barents Sea
When the November team returned to Longyearbyen, the next Nansen Legacy crew awaited the ship at the pier. Physical oceanographers swapped place with ecologists and chemists that went out to collect data from the Polar night season along the transect going from the ice-free waters in the (relative) south to the deep Arctic Basin in the north. Little is known about the biogeochemical conditions and living environment in the sea ice, the water and at the sea floor at this time of the year. The December expedition therefor brings important knowledge to the ongoing seasonal investigation. Overall, the Nansen Legacy looks back at a very successful year at sea in 2019.

The Nansen Legacy regularly brings journalists, photographers, and artists along on cruises. Here, artist Hege Holen Paulsrud describes how she experienced the research work on the mooring cruise in November 2019.

What would be the point of just messing around up there in the ice?

*Fridtjof Nansen thought. I'll get back to the answer.*

Because I am on a voyage around Svalbard with the Nansen Legacy research project. It's the Norwegian elite. Most likely the world elite. They really are good. These people work so that we can understand the sea, the ice, the air, and how everything is connected. They sit hour after hour with numbers and models, and test results. They twist and pull apart, devising complicated installations to be lowered down, and to be taken to exactly the right position in the ocean - hundreds, and sometimes thousands of meters deep. They are up all night to measure water temperatures and salt content and take water samples wherever we are. Well, not everywhere, but actually at carefully planned positions in the ocean. Positions, where they know they get the most out of the data and can read the ocean best. From an artist and non-scientist perspective, this is impressive. Everything they know. Everything they have been thinking about.
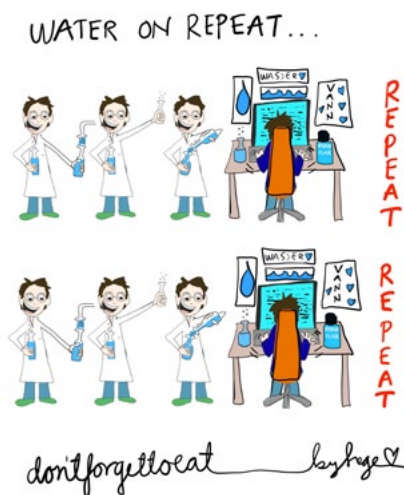
So that we can understand our globe, understand the climate and the changes in the climate. It will help us all to understand how we can save the Earth. That's what I feel. That they do a really important job. Each and every expert in their field. Things I had never thought of that could be investigated. It's so incredibly cool - I am so full of excitement and hallelujah mood. By the way, they are themselves too, full of hallelujah mood when things are going well. And they often do.

When you wait for a mooring (explanation a little further down) to be retrieved, some researchers can be conceived to be a little worried that things will not go the way they want. Because something may have happened - the mooring may have disappeared during the year or two it has been there. It has happened before, and will happen again. Then it is a bit okay to take the grief in advance to make sure there will be some. And one can find out all the theories about what has happened - in advance.
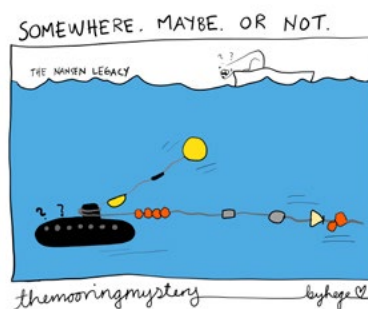
To us non-researchers:

MOORING: a long line, often hundreds of meters, full of instruments at different depths that measure e.g. water temperature, pressure, and salt content. These measurements tell the scientists a lot about what happens below sea level. That's how they read the sea. Several moorings at certain positions allow them to see the larger contexts, and thus understand the sea better. The mooring is set out with a heavy anchor at the bottom, and floatation elements along the line so that the mooring stands vertically in the water. Vertically - this is how it should stand and measure over a period, preferably a year or two.

But when you actually find it (which almost always happens), it can be difficult to see when it reaches the sea surface again. Because it is dark. And very icy. And the equipment is not huge. But expensive. Very expensive. The money is one thing, but the data that lies in the instruments - it's like Christmas Eve and your birthday on the same day.

Then it's nice to have technicians on board who know what they're doing. Who put on the right instruments last year. Who thought about how they could easily last a long time, how they should have just enough weight and buoyancy, how they could easily get back intact. And who have spare parts for everything you can imagine and not imagine that could be needed.

If there is something they don't have, then I think they just build it themselves. Easy.

But still, it can happen that the instruments that were released last year or the year before cannot be retrieved. And I dare say that the researchers do not have the same approach to that as the captain of the boat.


Fortunately, said with a good twinkle in his eye to ease the mood of sad scientists who have lost Christmas presents and birthday presents and a little of themselves there in the ocean. Because it looks like that's what they feel. Data they have been eagerly looking forward to using in research. Gone. There is nothing fun about it. I understand that too.

No, it's no secret that November at sea around 80 degrees north is dark. Occasionally wavy. And icy. And I can actually imagine that some researchers have thought of the idea that a November cruise cannot be compared to a cruise in April.

Fridtjof Nansen also had opinions on that. He who lived so much of his life as a marine scientist and in search of knowledge in the northern areas.

"I damn little want to be in this icy sea now ", he wrote. "This is a dog's life," he said of the marine scientist's existence.
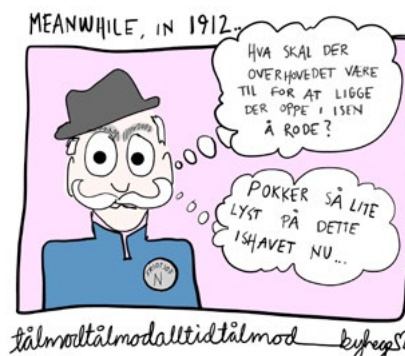
For Nansen, surprisingly, he often thought these thoughts, according to his books. But he also wrote that the consolation was that he had an important job to do. He was constantly searching for more knowledge, he never felt he was done, and he felt it was not going fast enough. He wanted to know more. Always.

He was convinced that the waters around Spitsbergen could be the key to greater understanding of the sea and the atmosphere. He thought polar research would be an input to understanding the climate around the globe, and his vision was:

"Let us explore the Arctic Ocean to its full extent from the surface to the bottom. Let's get to know everything about the physical conditions in those regions". So, he couldn't help it. The interest in solving the riddles of the sea weighed so much more than the fact that he would rather spent time in the forest.

He constantly felt that he had something undone that he was sure he could do better than most others could.

"What would be the point of just messing around up there in the ice?"

I am quite sure that the researchers onboard the research vessel Kronprins Haakon in November 2019 will arrive at the same answer as Fridtjof Nansen. For they are a bunch of such incredibly dedicated people, who all want to make an effort. The dedication is what shines through. The dedication for what they do, for achieving results. Their yearning for using the data they are here to collect. These are people who like to work. Who love the pursuit of knowledge of the sea. People who are here because they WANT.

That is THE NANSEN LEGACY.

Early career scientists

A new generation of polar researchers is needed to face and cope with the challenges of a rapidly changing Arctic. By the end of 2019, the Nansen Legacy employed 45 early career scientists, and worked together with 10 affiliated PhD students and post doctoral fellows.

- ● PhD students
- ● Post doctoral fellows
- ● Young researcher
- ● Affiliated PhD & PD
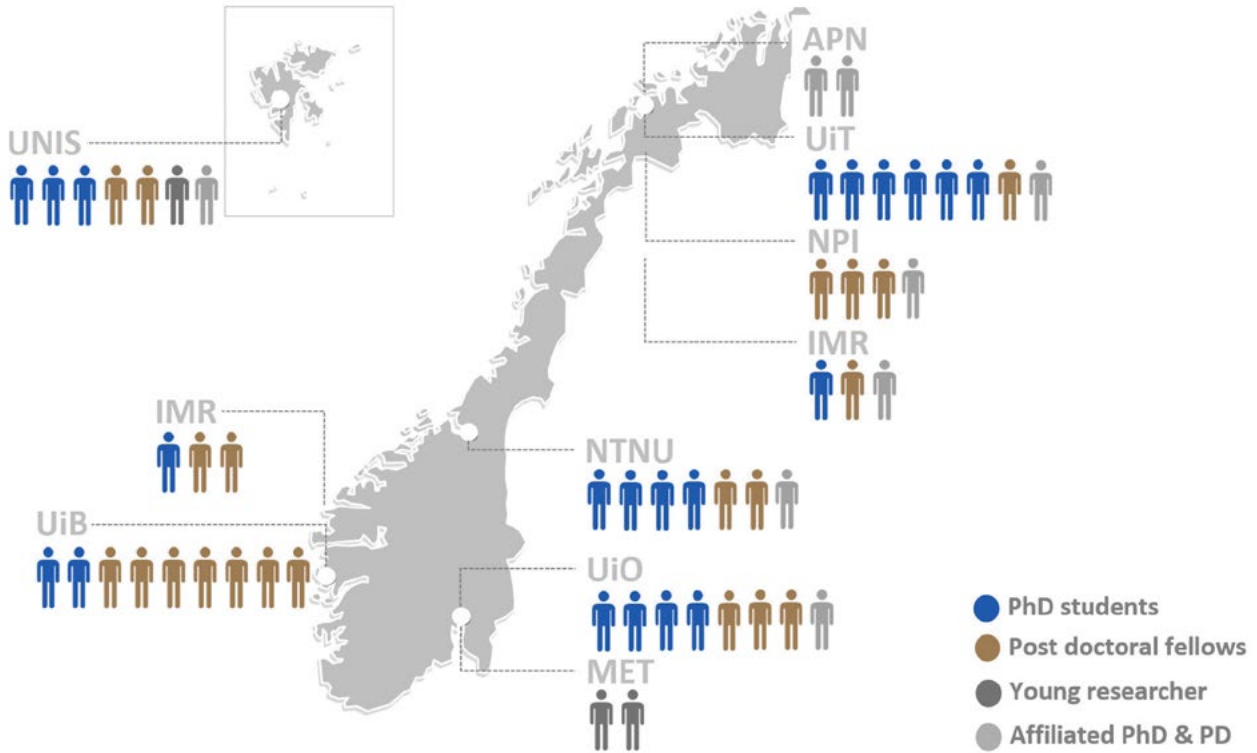
Σ 55   60%   PhD 21   PD 21

The Nansen Legacy facilitates the education of its early career scientists through workshops and summer schools in a multidisciplinary manner, giving highly needed cross-over competence.

Recruit Forum
The Recruit Forum is the annual meeting place for Nansen Legacy early career scientists. Here the recruits can discuss topics of interest. In 2019, the Recruit Forum was held for two days in Oslo, and used for getting to know each other, discuss and learn more about Plan S and the DORA declaration. The forum was additionally used to give training in science communication through filming of short elevator pitches.

Webinar series
The Nansen Legacy runs a webinar series on soft skills, such as presentation technices and popularizes science communication.
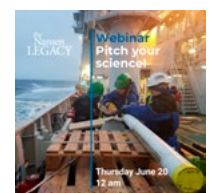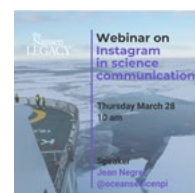
Meet some of our early career scientists

Studying the last ice age

PhD student Vårin Trælvik Eilertsen (UiT) During the last ice age, an ice sheet covered the Barents Sea. In the following warmer time-period, the area was characterized by a transition from glacio-marine to open-water conditions. The objective of Eilertsen's project is to reconstruct the paleo-environmental conditions in the northern Barents Sea from the last glacial until the present. The work will contribute to establish an understanding of the changes in marine Arctic climate and investigate how this climate has varied in the past. The results will provide key knowledge for a sustainable resource management in the European Arctic Seas.

Exploring the diets of small Barents Sea animals

PhD student Snorre Flo (UNIS, UiT) Answering «who eats who» is essential to understand the flow of energy and nutrients in an ecosystem. Due to recent developments in DNA sequencing and bioinformatics, ecologists now have an efficient tool to describe diets. Yet, only a handful of marine invertebrates have been studied using this methodology. With his PhD project, Flo will provide new perspectives on diets and preferences of small invertebrates from the Barents Sea region.
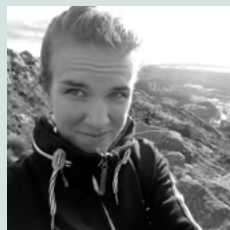
Predicting the Barents Sea primary production

Postdoctoral fellow Filippa Fransner (UiB) The Barents Sea temperature and cod stock has been shown to be predictable several years into the future. This predictability comes from the long-term memory of the North Atlantic and Norwegian Atlantic currents, bringing large amounts of heat to the Barents Sea from the South. Fransner is working with the Norwegian Climate Prediction Model to investigate how this predictability can be translated into ocean biogeochemistry and primary production, and eventually if it can be connected to ocean ecosystems and predictions of fish stocks.

Acoustic detection of macrozooplankton

Postdoctoral fellow Tom Van Engeland (IMR) Zooplankton represents the trophic connection between the base of the food chain and higher trophic levels, such as fish and mammals. Therefore, effective fisheries and ecosystem management requires information on their seasonal dynamics and spatial distribution. Van Engeland is developing methods to identify macrozooplankton species and quantify their biomass using ship-borne echosounders that continuously measure the entire water column throughout the cruises. This acoustic information complements the sparse point sampling with plankton nets by filling in the spatial gaps.

Structure and function of benthic communities

Affiliated PhD student Èric Jordà Molina (UiN) Molina studies the species diversity and processes such as respiration rates and carbon uptake rates of the soft-bottom benthic communities along the Nansen Legacy transect on a seasonal basis. Molina also investigates long-term responses of macrofaunal communities in the northern Barents Sea where ocean warming and changes to the vertical fluxes of organic matter in this region will most likely lead to changes in the remineralization and biogeochemical processes in the sediments, with consequences in the carbon flux processes for the ecosystem.

Mercury accumulation in Arctic fish species during the Polar night

Master student Anjali Gopakumar (UiO) Mercury is one amongst the many anthropogenic and natural pollutants that is negatively affecting the Arctic food web and ecosystem. However, knowledge of mercury levels in Arctic species during the late autumn and winter is limited, primarily due to the difficulty of obtaining data during this long and dark period. Thus, the overall aim of Gopakumar's study is to quantify and document the accumulation of mercury in key Arctic fish species in the northern Barents Sea, during the Polar night.

The trace hunter

Photo: Christian Morel / christianmorel.net

Nicolas Sanchez is a postdoctoral fellow at NTNU. In this interview, Nicolas explains his tedious search for traces.

You have been part of the Nansen Legacy almost from its start. What is your best experience with the project so far?

The Nansen Legacy is a project covering most, if not all domains of oceanography within one of the most contingent topic of our time, so it is exciting to be taking part in such broad endeavor. It also means that you get to share and connect with scientist nationwide. This integrates the best of this experience.

On cruises, you often go in a white bunny suit and work in a plastic bubble. Why is that?

This is one of the most interesting and at the same time challenging aspects of working with trace elements in marine environments. Because of their physic-chemical properties, trace elements are present in such low concentrations, that it was not possible to accurately measure the concentrations of these elements for decades. Most working platforms at sea are metal structures, which means that the risk of contamination for elements such as iron, copper, or zinc is high. By using plastic instead of metal structures, clean air filters, and antistatic lab suits, we avoid most of suspended particles in the working environment and therefore minimizing the risk for contamination.

Could you give a feeling for what kind of concentrations we are talking about for trace elements in the sea?

Iron and other bio-essential trace elements have extremely low solubility in seawater, which is why their concentrations are extremely low in the sea, expressed as parts per billion (ppb). For comparison, five drops of ink in about 200 L of water is the equivalent of 1 part per million (ppm). One ppb is 1000 times less than that.

If trace elements are only found in such infinitesimal amounts in the sea, why should we care about them?

Elements like iron are vital for photosynthetic organisms and limit primary production in 30-40 % of marine environments. Through the evolution of marine life, living organisms have favored several transition elements, mainly because of the versatile biological functions, but also because these elements were abundant in the physic-chemical conditions of early oceans (reductive environments). In today's ocean (oxygenic environments), these elements are very scarce and therefore marine life (i.e. marine microbes) is faced with the challenge to constantly acquire elements that perform essential functions.

The Nansen Legacy is an interdisciplinary project. Have you in your work profited from the other disciplines?

There is definitive benefit from the other disciplines. The field of marine trace metal biogeochemistry is a cross-disciplinarily domain, as its name suggests. Although trace metals in the ocean have a relevant role of its own - as tracers for geo-physical processes - we are most focused on the role of these elements for the basis of marine life, i.e. all the processes which trace elements affect the uptake of nutrients, ecosystem structure (bacteria and phytoplankton), and ultimately primary production. Therefore, there is definitely a benefit to share data and information with the other scientists. Yet, given the rhythm, pace of cruises, and the overall timeframe in which the fieldwork is arranged, it is challenging to be able to interact and produce cooperative work, when processing the basic data constitutes the priority..

What do you think you will take with you from the Nansen Legacy?

An overall enriched experience both personally and professionally.

Postdoc Nicolas Sanchez and PhD candidate Stephen Kohler are dressed in full bunny suits to limit the possibility of contaminating their water samples. Photo: Christian Morel / christianmorel.net

Outreach

Nansen Legacy scientists used the project's second year to communicate their research and the project's vision to a large audience, ranging from school kids to international stakeholders. Both the young and more established researchers appeared in media, contributed with a number of newspaper chronicles, a research blog and a large variety of public talks.

10 000 readers

Our researchers write regularly about their work on Forskning.no. In 2019, the Nansen Legacy also started a blog on the newly established English platform ScienceNorway. no. The Nansen Legacy blog series has about 10 000 readers, which followed the 35 blog posts during the past year. The blog posts range from more personal descriptions of life at sea to stories about the scientific work within the project.

Activities and results was also conveyed to a wider audience via national and international newspaper articles, radio and TV. The Nansen Legacy also communicates its work on social media like Instagram, Facebook and Twitter.

A night in Oslo

During the National Research Days, the Nansen Legacy invited to an evening with popular science talks at the Literature House in Oslo. The talks were given by Nansen Legacy researchers at UiO and focused on different research topics of the project - from research on ocean currents to environmental toxins and changes in food web structure in the Barents Sea and adjacent Arctic Ocean.

The National Research Days were also used for other outreach activities, such as stands at Science Fairs in Oslo and Tromsø and a small photo exhibition.

Nansen Legacy activities during research days in Oslo, 2019
Photo: Nina Knudtzon

With a small photo exhibition, the Nansen Legacy showed examples of different research activities conducted onboard *RV Kronprins Haakon*. The exhibition was part of outreach activities at UiT and the Fram Centre in Tromsø during the National Research Days.

Deployment of a sea glider. Photo: Christian Morel / christianmorel.net

International collaboration

Although a Norwegian research project, the Nansen Legacy is tightly connected to the international Arctic marine research arena through collaboration with several other projects, as well as through contribution to relevant international science comittees and organisations.

Research cruises, analysis and data sharing

The Nansen Legacy and several of the UK programme Changing Arctic Ocean projects have developed collaboration to complement investigations in the Barents Sea. This includes joint participation in cruises, support in mooring retrievement, mobility to collaborate on sample analysis, and joint participation on meetings and workshops. Universities in Spain and France and research centers in USA have been involved in student or researcher mobilities for sample analysis or model optimization. The Institute of Oceanology Polish Academy of Sciences is an important collaborator on biodiversity analysis and community composition of ice algae, phytoplankton, zooplankton and macrobenthos. Gelatinous plankton has been collected for collaboration both with AWI, Germany and associated project members at NTNU. For data collection in the Russian sector of the Barents Sea, collaboration with the Murmansk Marine Biological Laboratory has been crucial.

Strengthening synergies with MOSAiC

Seasonality in the Arctic constitute a knowledge gap, and the Nansen Legacy will carry out synoptic seasonal cruises with the international drift experiment, the MOSAiC campaign, in 2019/2020. To ensure that the two projects obtain comparable and contiguous data, Nansen Legacy researchers participated in the MOSAiC Workshop in Postdam, Germany to clarify consistency in observations including airborne observations, remote sensing, physical and biological measurements in the field.

Nansen Legacy and the Pan-Arctic context

Dialogue and collaboration across the Arctic Ocean and neighbouring regions are keys to understand the changing Arctic Ocean and the role of the Barents Sea. Examples of integrating the Nansen Legacy in a Pan-Arctic context include presentations of the project and participation at various conferences and dialogue meetings, such as the Study of Environmental Arctic Change (SEARCH) conference "Arctic Futures 2050" in Washington DC, in September 2019, the Arctic-Sub-Arctic Ocean Fluxes (ASOF) in Copenhagen, the IMBeR conference in Brest, France, and Society of experimental toxicology and chemistry in Toronto, Canada. The project has also been presented at the Pacific Arctic Group (PAG) and the Arctic Science Partnership (ASP) which provide mutual information exchange and coordination with the Canadian, Danish and Greenlandic Arctic research communities.

Scientific Advisory board

The Nansen Legacy Scientific Advisory board consists of renowned international experts who will contribute advice in order to ensure the scientific quality and successful completion of the project. The members are selected based on their scientific expertise, research activities and their geographic distribution to provide scientific advice on a broad disciplinary and geographic basis. Countries represented in the Scientific Advisory board include Germany, USA, Canada, Greenland, Finland, UK, and Denmark. The members' expertise spand from physical drivers, through structure and function of Arctic marine ecosystems, to remote sensing and modeling.

"Both Nansen Legacy and our NERC-funded ChAOS project are conducting research in the Barents Sea, which could create either friction or synergy. I am extremely happy that the latter is the case, and all Norwegian colleagues I have interacted with to date have been extremely helpful and forthcoming – a true international collaboration. Researchers from both project communicate closely with each other, we were very kindly offered two berths on a 2018 Nansen Legacy cruise, offered berths on our ChAOS cruises in return, and by attending each other's project meeting we ensure that the communication keeps flowing. With ChAOS terminating in 2021, I very much hope that this collaboration will persist beyond the lifetime of our project, leading to a more complete understanding of the quickly changing Barents Sea."

Christian März
PI of the ChAOS project
University of Leeds, UK

Near the North Pole

MOSAiC is an on-going ice drift campaign led by the Alfred Wegener Institute in Germany. For this campaign, RV *Polarstern* was frozen into the Arctic sea ice, and is now drifting with an ice flow across the Arctic Ocean for one year.


Polarstern during the MOSAiC drift across the Arctic Ocean.
Photo: Alfred-Wegener-Institut / Esther Horvath (CC-BY 4.0)

The drift is in the spirit of Nansen's campaign with RV *Fram* in 1893, however considerably up-scaled by using the 120 m long RV *Polarstern* with an international team of about 60 researchers from more than 20 countries on each cruise leg. Nansen Legacy postdoctoral fellow Lasse Mork Olsen from UiB joined the drift from November to March, The drift is in the spirit of Nansen's campaign with RV *Fram* in 1893, however considerably up-scaled by using the 120 m long RV *Polarstern* with an international team of about 60 researchers from more than 20 countries on each cruise leg. Nansen Legacy postdoctoral fellow Lasse Mork Olsen from UiB joined the drift from November to March,

Going back in time

One integral part of the Nansen Legacy project is elucidating the natural variability of sea ice and Atlantic Water inflow over longer (decades to millennia) time scales based on the sedimentary record of the Barents Sea, as a requirement for accurate future climate projections.
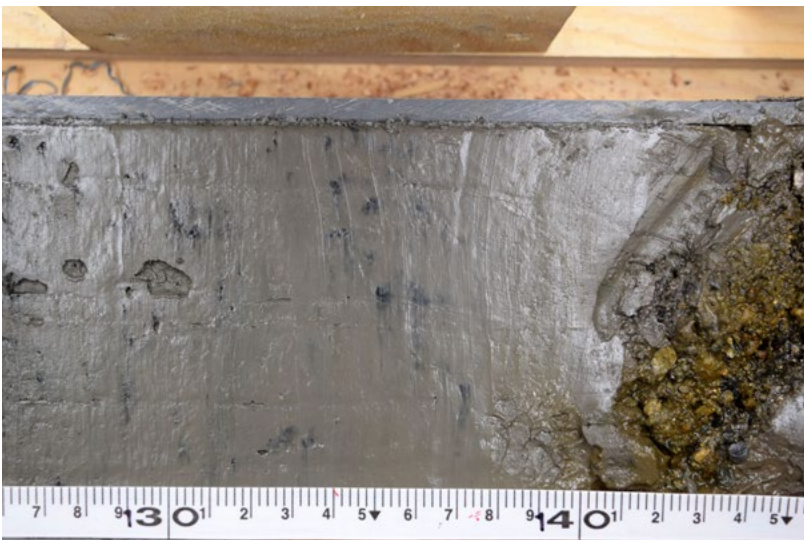
Sediment core from the northern Barents Sea facilitates international collaboration.
Photo: Vårin Trælvik Eilertsen

To achieve this aim, Nansen Legacy postdoctoral fellow Anna Pienkowski from NPI investigates preserved molecular fossils (highly-branched isoprenoid biomarkers or "HBIs") produced by diatoms, which are found in the sediments of the Barents Sea. The method Pienkowski is using was developed by Prof. Simon Belt at the University of Plymouth, UK. It was therefore natural for Pienkowski to take her samples from the Nansen Legacy paleo cruise in 2018 along to the UK. In close collaboration with Prof. Belt and his research group, Pienkowski analyzed sediment cores for HBIs produced by both obligate sea ice diatoms and open-water phytoplankton. These data can be used together to reconstruct seasonal spring sea ice, the seasonal sea ice edge, and phytoplankton blooms at the marginal ice zone. Thus far, this work has encompassed two visits to the University of Plymouth for training and research, with another visit scheduled for later in 2020.

Sampling of sea ice melt pond water during the seasonal cruise in August 2019. Jack Garnett (holding the bucket) is a PhD student at Lancaster University, UK, who joined the cruise as part of the collaboration between the Nansen Legacy and the british project EISPAC.
Photo: Christian Morel / christianmorel.net

Interaction with society

The Nansen Legacy is first and foremost a research project. However, the full value of a successful research project depends on its overall impact on society. To what extent can the new knowledge help society overcome the challenges posed by the rapidly changing climate? The Nansen Legacy interacts with society in several ways, and works towards synthesizing and communicating its research findings in a way that facilitates dialogue with users also outside of the scientific community. Being the first of its kind as a cross-disciplinary, large national endeavor, the Nansen Legacy is also a pioneer with respect to synergies within national research infrastructures and technological development.

Illustration: Juliette Planque

Stakeholder workshop on the future Barents Sea, risks, mitigation and adaptation options

Stakeholders in the Arctic have a desire to know what the future will bring. They were therefore taken on a joint exploration of the possible states of the Barents Sea by the horizon 2050.

The Nansen Legacy, together with the project BarentsRisk funded by the Norwegian Research Council, organized a stakeholder workshop where a range of future scenarios for the Barents Sea were presented. Scientists and stakeholders then engaged into discussions about the risks associated to these scenarios and the possible ways to mitigate or adapt to these risks. The workshop was attended by 7 researchers and 10 stakeholders, and was organized into four different sessions: 1) risks and ecosystem services, 2) futures of the Barents Sea, 3) group work to explore how risk may change under future scenarios, and 4) science-stakeholder interactions.

Enhance collaboration and dialogue between scientists, indigenous people and policy makers

In order to enhance collaboration and dialogue between Arctic scientists, indigenous knowledge holders and policy makers from all levels of the government, the Study of Environmental Arctic Change (SEARCH) designed the conference "Arctic Future 2050", which was held in Washington in September.

The Nansen Legacy participants contributed to two panel debates. Marit Reigstad discussed how scientists and management work together to ensure sustainable fisheries in a debate entitled "Barents Sea fisheries – informing management under rapid change". Paul Wassmann participated in a panel discussing the socioecological "Implications of a changing marine ecosystem". Science, management, indigenous people and policymakers were represented, and provided interesting perspectives and discussions.

Photo: Christian Morel / christianmorel.net

Reconciling scientists and non-scientists by modelling

Sound participatory management requires that different actors – from fishermen to scientists – can understand and trust one of the most important tools in fisheries management: numerical models. This implies that assumptions behind the models are presented in a clear, honest and transparent way.

Models help us to make sense of complicated data or to test our hypotheses. For this reason, they are increasingly used in studies and analyses that support fisheries and ecosystem management decisions. When used to study complex systems, like the Barents Sea food-web, models can become themselves rather complicated. The modelling principles and terminology used by modellers are sometimes barely accessible to non-specialists, therefore hindering a fruitful dialogue. In a newly published article, Nansen Legacy scientists, Benjamin Planque, proposes the use of a new kind of simple models as a practical step to enable modellers and non-modellers alike to better share their understanding of how model assumptions, data and model outputs are linked.

Chance and necessity
The proposed model approach is based on the principles of chance and necessity (CaN), and explicitly acknowledges our limited capacity to observe and model ecological processes. A central element of this model approach is that the model outputs cover a range of possible ecosystem states and dynamics, rather than striving to deliver one best estimate. The existence of these multiple possibilities represents the starting point for discussions among scientists, managers, and stakeholders.

The Barents Sea model
Using a simplified representation of the Barents Sea food-web and annual field-based biomass estimates, Planque and his coworker Christian Mullon constructed an explorative CaN model for the Barents Sea. The objectives for this model were to learn about the controls of the system while recognizing the limits to our understanding

and to our observational capabilities. With help of the model, Planque and Mullon investigated how species and trophic interactions may have varied in the past and to which degree these variations can explain the changes in the Barents Sea ecosystem that have been observed. The Barents Sea CaN model is proposed as a quantitative tool for the integrated ecosystem assessment for the Barents Sea, conducted by ICES, the International Council for the Exploration of the Sea.

"The outputs of the model provide many possible 'histories' of the Barents Sea food web dynamics. These can serve as the basis for the discussion between modellers, managers and stakeholders."

Benjamin Planque, IMR

Reference:
Planque, B. and Mullon C. (2019). Modelling chance and necessity in natural systems. ICES Journal of Marine Science, 1-16. doi:10.1093/icesjms/fsz173

Societal impact

The overarching goal for the Nansen Legacy project is to provide a better scientific basis for the sustainable management of the northern Barents Sea and the adjacent Arctic Ocean. Some examples below illustrate the span of activities.

Ice distribution and weather forecasts
New insights show how natural variations in the north-flowing Norwegian Atlantic current impacts the extent of sea ice cover from year to year and enable predictions about future changes in the sea ice cover. This has ramifications for ecosystem function and fisheries, as well as future accessibility for ship traffic. Model forecast and verification development for the weather and sea ice forecasting system for the European Arctic have been improved by developing tools for assessing the quality of sea ice edge maps, contribution to the development of seasonal sea ice edge forecasts, and discovery of the important insulating effect of snow on top of ice.

Added value from historical data
In addition to collection of new data through sampling and measurements, Nansen Legacy researchers invest time and expertise in utilizing historical data sets to gain new insight. This applies to the physical oceanographical research, improved weather forecasting, and also for understanding the consequences of a changing climate for the Barents Sea food web. The study of year-to-year variations in the biomasses of various fish species and zooplankton groups would not have been possible without the 35 years long comprehensive data collection on fish and other animals in the Barents Sea carried out by the Institute of Marine Research.

Future scenarios and dialogue with stakeholders
Future sustainable management of the northern Barents Sea and the adjacent Arctic Ocean is highly dependent on the efficient transfer of knowledge and a good dialogue between scientists and the various stakeholders in the Arctic. Whether the user is the petroleum-, fishing- or tourism industry, indigenous people, or international or governmental management authorities, the Nansen Legacy is engaging in this dialogue. Through workshop discussions about risks associated to different scenarios of a future Barents Sea, through contributions to national and international panel debates, and by proposing quantitative tools for integrated ecosystem assessment for the Barents Sea to ICES, the project contributes to communicate new scientific basis to the society and to policy makers in a comprehensive way.

Robotics and biological dynamics
The development of automatic underwater robots that can "think for themselves" and follow gradients in, for instance, the concentration of chlorophyll, allows researchers to resolve small scale variability in phytoplankton biomass related to hydrographic conditions in the water column. This is a giant step forward towards a better understanding of the smaller scale structures that influence plankton dynamics and production.

Coordination across institutions
In addition to the purely scientific advances, the successful interdisciplinary and cross-institutional cruises with the new icebreaker *RV Kronprins Haakon* in 2019 demonstrate how the Nansen Legacy realize a potential for better use of scientific infrastructure. The development of common sampling protocols, and joint data management using national and international structures such as the National Infrastructure for Research Data (NIRD), UNINETT SIGMA2 and Svalbard Integrated Arctic Earth Observing System (SIOS), is likewise a good examples of the synergetic gain that is achievable within one project to optimize the use of marine Arctic research infrastructure within Norway.

International connections
The Nansen Legacy has a direct impact beyond national borders through collaboration with other international projects, via joint cruises, mobility, exchange of data, and the contribution of Nansen Legacy researchers to international work in the Arctic Monitoring and Assessment Program (AMAP), the International Arctic Science Committee (IASC), Conservation of Arctic Fauna and Flora (CAFF) and the World Meteorological Organization (WMO).

Nansen Legacy in IPCC report
Nansen Legacy scientist Lars Henrik Smedsrud from UiB was one of the authors behind chapter 3 "Polar regions", in the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate, which was launched 25 September 2019. The broad conclusion from this report is that there are major changes in both Antarctica and the Arctic, with the increasing global temperatures leading to increased ice melting and sea level rise. The scientific IPCC reports are the most comprehensive and important basis for international climate policy.

Photo: Christian Morel / christianmorel.net

New method for weather forecasting in the Arctic

By taking into consideration the insulating effect of snow on top of sea ice, Nansen Legacy researchers have improved weather forecasting capabilities in the Arctic.

The air in the Arctic is freezing cold. Under clear skies during the arctic winter, temperatures in the air near the ice surface can drop to minus 40 degrees Celsius.

Sea ice in the Arctic forms as a floating layer of frozen seawater. The water beneath the ice gets no colder than about one degree below zero. That means that the sea is considerably warmer than the air above it, which results in heat being transported from the ocean to the atmosphere.

Snow on the ice makes the air colder

Sea ice is often covered by a layer of snow. Snow provides excellent insulation and impedes the transfer of heat from the water beneath the ice, to the air above it. In fact, the layer of snow insulates seven times more effectively than ice of the same thickness. Because of the strong insulating effect of snow, the air above snow-covered sea ice will generally be colder than the air above bare ice, all other factors being equal.

Nansen Legacy researchers Yurii Batrak and Malte Müller from the Norwegian Meteorological Institute have examined various weather models currently in use around the world – models that form the basis for weather forecasting. None of the models had fully taken into consideration the fact that sea ice often has a layer of snow on top.

Five to fifteen degrees too warm

In their study, Batrak and Müller compared forecasts from different weather models with the temperatures actually measured on the surface of the ice. This temperature is closely related to the air temperature just above the ice.

The improved weather model that takes into account the presence of snow on the ice was the only model that accurately predicted air temperature over the ice. All the other models that the researchers examined indicated temperatures higher than measured, between 5 and 10 degrees too high.

As a result of this study, an improved weather model that takes the snow layer on the ice into consideration has now been adopted by Yr (yr.no) - a Norwegian web site for weather forecasts - for use in Arctic areas.

"This work is a step on the way towards coupled ocean, ice, wave and atmospheric forecasting systems."

Malte Müller, MET

Reference:
Batrak, Y. and **Müller M.** (2019). On the warm bias in atmospheric reanalyses induced by the missing snow over Arctic sea-ice. *Nature Communications*, 10: 4170. doi:10.1038/s41467-019-11975-3

This is a short version of an article first published in sciencenorway.no
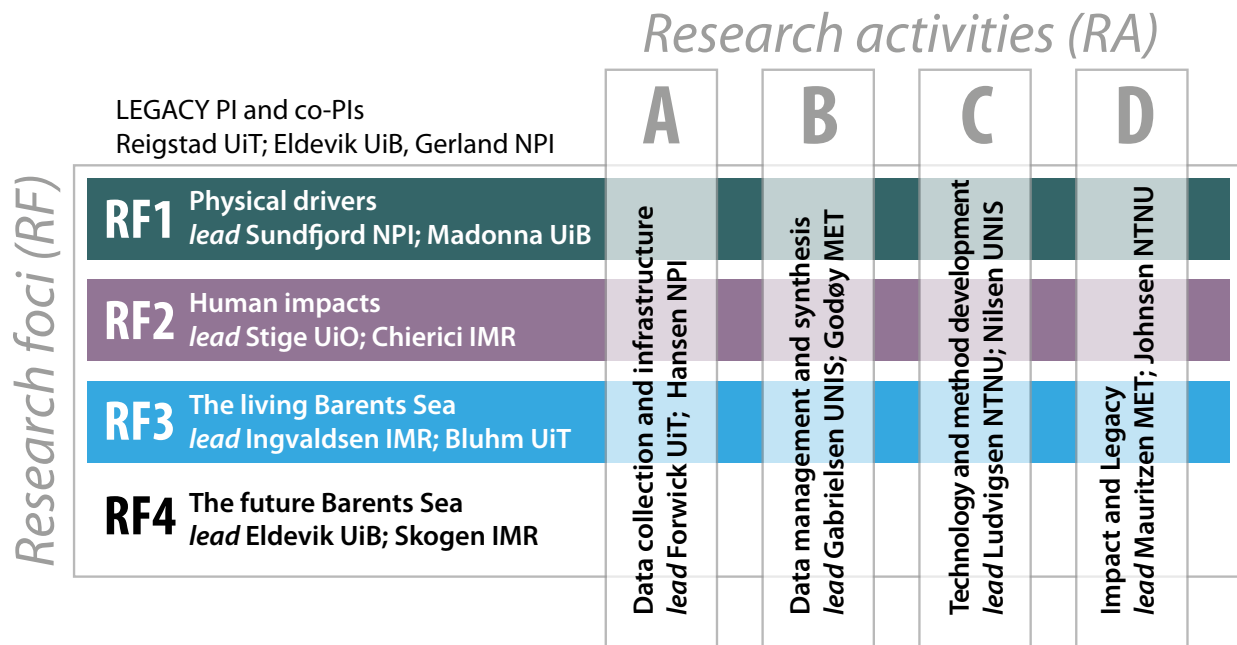
Sampling of fish blod. Environmental pollutants have for long reached the Arctic where they accumulated in plants and animals. Ecotoxicological studies are therefore part of the Nansen Legacy. Photo: Christian Morel / christianmorel.net

Organisation

The Nansen Legacy is a collaboration between ten Norwegian research institutions, currently involving over 200 project members. Members include PhD students, postdoctoral fellows, researchers, technicians, engineers and communication advisers. In addition to the scientific leadership, the project has a Board, as well as a Scientific Advisory board.

Research activities (RA)

LEGACY PI and co-PIs
Reigstad UiT; Eldevik UiB, Gerland NPI

Research foci (RF)

		A	B	C	D
RF1	**Physical drivers** *lead* Sundfjord NPI; Madonna UiB				
RF2	**Human impacts** *lead* Stige UiO; Chierici IMR				
RF3	**The living Barents Sea** *lead* Ingvaldsen IMR; Bluhm UiT				
RF4	**The future Barents Sea** *lead* Eldevik UiB; Skogen IMR				

A: Data collection and infrastructure *lead* Forwick UiT; Hansen NPI
B: Data management and synthesis *lead* Gabrielsen UNIS; Godøy MET
C: Technology and method development *lead* Ludvigsen NTNU; Nilsen UNIS
D: Impact and Legacy *lead* Mauritzen MET; Johnsen NTNU

The Research Foci (RF1-4) represents "what" science the Nansen Legacy is investigating, and the Research Activities "how" (A-C), including impact and legacy in the public domain (D).

Project leaders

Marit Reigstad

Prof. Reigstad is the principal investigator (PI) of the Nansen Legacy. She is a marine ecologist interested in connectivity, including physics and biology, surface and deep waters, and regional connections. She has led several interdisciplinary projects and expeditions on Arctic marine ecosystems, and is active in science communication. Reigstad has been involved in international science planning since 2004, through ICARP and IASC. She serves on Liason- and evaluation panels and scientific advisory boards.

Tor Eldevik

Prof. Eldevik is co-PI and also leads the 'The future Barents Sea' Research Focus. Eldevik generally explores the northern seas' role in past, present, and future climate, using a combination of theory, observations, and numerical models. The combination is also Eldevik's approach in communicating his research and other aspects of climate change to students and the general public. Present commissions of trust include contributing to the European Academies' Science Advisory Council (EASAC) and JPI Oceans/RCN.

Sebastian Gerland

Dr. Gerland is co-PI of the Nansen Legacy. He is currently working with sea ice physics research and monitoring in the context of Arctic climate research. Beyond his involvement in the Nansen Legacy, he is leading and participating in other national and international projects, including the Norwegian Polar Institute's long-term Arctic sea ice monitoring, and projects funded by the Research Council of Norway (e.g. HAVOC-MOSAiC and CIRFA SFI). Gerland is also active in climate assessments (currently IPCC's 6th assessment report and the NOAA Arctic report card).

RF1 Physical drivers

Arild Sundfjord

Erica Madonna

The Barents Sea is a significant gateway with inflow of Atlantic water to and Arctic water from the rapidly changing Arctic Ocean. A firm understanding of the physical climate system in this region is a fundamental building block for any sustainable management, and prognostic models for the Barents Sea and the adjacent Arctic. *Objective:* Determine contemporary and historical environmental conditions and internal regulation mechanisms, and based on this improve the understanding of physical system response to environmental changes.

RF2 Human impacts

Leif Christian Stige

Melissa Chierici

Arctic areas are exposed to climate change as well as other human influences, such as ocean acidification, pollution, and commercial fisheries. *Objective:* Improve our understanding of how human activities influence the northern Barents Sea ecosystem.

RF3 The living Barents Sea

Randi Ingvaldsen

Bodil Bluhm

Biodiversity, ecosystem functioning, and environmental forcing are inherently and intricately linked in any ecosystem, with their relationships shaped by region, habitat and temporal dynamic. *Objective:* Build critical understanding of how organisms in the northern Barents Sea ecosystem and adjacent slope respond to current and changing environmental conditions on the species and community levels by identifying characteristic communities, delineating the relevant environmental forcing factors that structure these communities across seasons and habitats, estimate their production and rate-limiting factors, and detail trophic and other ecosystem linkages.

# RF4 The future Barents Sea

Tor Eldevik

Morten Skogen

The sustainable management of resources and environment is fundamentally about foresight. It depends critically on our capacity to observe, understand and eventually predict the transitions between past, present and future states of weather, climate, and the marine ecosystem. *Objective:* Assess the state, predictability, and associated uncertainties of the Barents Sea weather, climate, and ecosystem.

RA-A Data collection and infrastructure
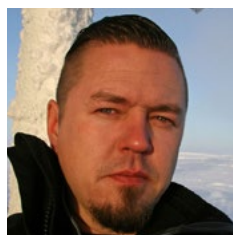
The Nansen Legacy will carry out multi-disciplinary research using extensive ship-based field expeditions. This fieldwork is based on a coordinated use of the Norwegian research vessels, particularly the new Norwegian ice-going research vessel *RV Kronprins Haakon*. *Objective:* Facilitate, coordinate, and integrate the collection of new observational data, proxy data, and modeling output across the *Nansen Legacy* project.

Matthias Forwick   Håvard Hansen

RA-B Data management and synthesis
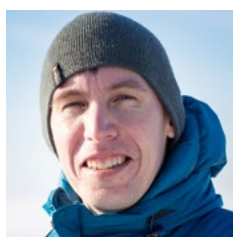

Structured data management is a pre-requisite for data exploitation; the act of exploration of the full potential of scientific data as individual datasets, in a discipline specific context, and in an interdisciplinary perspective. *Objective:* Ensure longterm preservation of all relevant data, with unified, open data access through services that provide for simplified data exchange and responsible data reuse, including proper attribution.

Tove Gabrielsen   Øystein Godøy

RA-C Technology and method development

Enabling technology for mapping and monitoring of extreme environments is essential for modern future management and sustainable utilization of the Barents Sea. Arctic conditions require a high degree of autonomy and integrated observation systems to reduce operation time and weather dependency, and to enable measurements in all seasons. *Objective:* Study and develop reliable and robust autonomous platform solutions for smarter measurements and sampling for detection and analysis, to improve modeling based on remote sensing with impacts on the ecosystem or human activity in the Barents Sea.

Martin Ludvigsen   Frank Nilsen

RA-D Impact and legacy

A major task for the Nansen Legacy is to promote interest for and increase the general knowledge about Arctic marine systems. To accomplish this, it is necessary to reach out to the scientific community and the general public, to establish dialogue with users and stakeholders, to educate the next generation of scientists, and to enhance the focus on innovation as potential products of basic science. *Objective:* Ensure outstanding national and international impact from the research carried out, to ensure a lasting legacy of the project, and to enhance the benefit and relevance to society.

Cecilie Mauritzen   Geir Johnsen

Nansen Legacy Annual meeting, October 2019. Photo: Magne Velle

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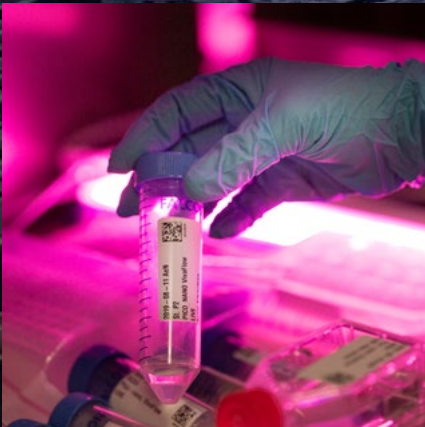
Nansen Legacy at work.
Large photo: Arild Sundfjord
Small photos: Christian Morel / christianmorel.net

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Whiteout. Returning from work on the sea ice to *RV Kronprins Haakon* in August 2019. Photo: Christian Morel / christianmorel.net
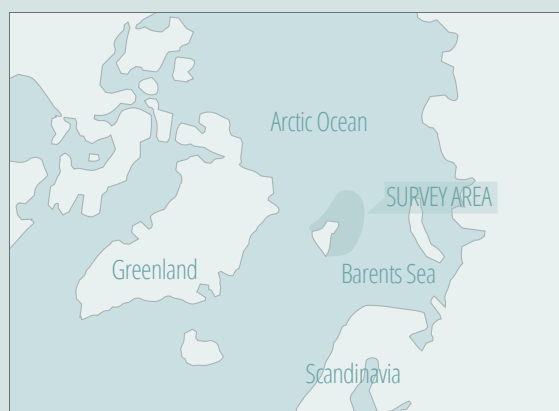
The Nansen Legacy in numbers

6 years

The Nansen Legacy is a six-year project, running from 2018 to 2023.

250 people

Currently, there are about 210 researchers working with the Nansen Legacy, of which 50 are early career scientists. In addition, 40 persons are involved as technicians, project coordinators, communication advisers and board members.

1 400 000 km² of sea

The Nansen Legacy investigates the physical and biological environment of the northern Barents Sea and adjacent Arctic Ocean.

Arctic Ocean

SURVEY AREA

Greenland

Barents Sea

Scandinavia

10 institutions

The Nansen Legacy unites the complimentary scientific expertise of ten Norwegian institutions dedicated to Arctic research.

>10 fields

The Nansen Legacy includes scientists from the fields of biology, chemistry, climate research, ecosystem modelling, ecotoxicology, geology, ice physics, meteorology, observational technology, and physical oceanography.

50/50 financing

The Nansen Legacy has a total budget of 740 million NOK. Half the budget comes from the consortiums' own funding, while the other half is provided by the Research Council of Norway and the Ministry of Education and Research.

>350 days at sea

The Nansen Legacy will conduct 15 scientific cruises and spend more than 350 days in the northern Barents Sea and adjacent Arctic Ocean between 2018 and 2022. Most of these cruises are conducted on the new Norwegian research icebreaker *RV Kronprins Haakon.*