The Nansen Legacy

Annual Report
2022

The Nansen Legacy Report Series 40/2023

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Statement from the Board

At the end of 2022, the Nansen Legacy can look back on five years of joint research effort from 230 scientists and early careers to establish a knowledge base for the seasonally ice-covered northern Barents Sea and the adjacent Arctic Basin. Several early careers have now finished and moved on. An extensive field work to collect new data is completed, new combinations of technology has improved our measurements, improved observations and model performance have improved weather- and sea ice forecasts as well as the predictive capacity of future climate and ecosystem conditions.

In the final phase of the project, integration of the new knowledge across approaches, scales and disciplines is in focus. This represents an important step towards the project goal of building a more comprehensive understanding of the Barents Sea, the driving forces and responses, and how that impacts the living Barents Sea. The synthesis is driven by task force groups on seven themes presented in more detail in this report. The planned products include synthesis papers, special issues, and fact sheets to target to different user groups, including management, to make the research useful. A final international symposium, "Towards the new Arctic Ocean – past, present, and future" in November 2023, aims to gather a Pan-Arctic community to discuss how the regional knowledge achieved can be connected to improve our understanding of the Arctic Ocean.

Following the recommendation from the mid-term evaluation, the Board was extended with two new members in 2022, representing the early careers and the user group. Both contribute with new and complementary perspectives and have been a valuable extension.

Acknowledging the success of the Nansen Legacy project collaboration for remote and complex research challenges, an initiative to develop a complementary initiative on the Future Arctic Basin has been taken by the Nansen Legacy Board. This will sustain the rewarding collaboration for future Arctic research. ■

Photo: Malte Müller

Foreword from the leaders 2022: The Nansen Legacy – an innovative voyage

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

At the end of 2022 we can look back on five years of unique collaboration in Norwegian Arctic marine science. We have started on the final phase of the immense Nansen Legacy project, that has the same size as a research program.

Following the tradition of the Pro Mare program that built a knowledge base for the ice-free part of the Barents Sea in the 1980s, we have extended the joint research efforts in the rapidly changing seasonally ice-covered Northern Barents Sea.

Building a knowledge base for the future sustainable and ecosystem-based management in this area requires specific knowledge on the climate, the physical system and ecological processes. Therefore, it is essential to understand how the three systems interact and how our human activities affect them. By precisely conducting research across disciplines and institutions with different but complementary Arctic marine expertise from 230 scientists, we have produced datasets from observations and model simulations that can help us build a more comprehensive understanding.

Summarising the project data collected since 2018 demonstrates how complementary the utilized infrastructure was: 337 days on *RV Kronprins Haakon* and other research vessels were accompanied by 502 days of glider measurements, 13 694 days of mooring measurements, and 16 days with helicopter flights. Though these infrastructures facilitate different types of data sampling, the combined data sets offer a comprehensive temporal and spatial coverage.

By the end of 2022, 154 peer reviewed publications have been published in the Nansen Legacy and of these, 63 were from 2022. We provide both glimpses and more details in this annual report. To build integrated and holistic knowledge, we used (among others) focused studies on animals at methane seeps, detailed reviews documenting the increased warming of the Arctic atmosphere and the ocean compared with global mean, and the effect of multiple stressors like contaminants and a warmer climate on Arctic organisms and ecosystems. Additionally, Nansen Legacy scientists produced an article on a new sea ice rheology. The latter represents an important leap in climate models because it allows a much more realistic representation of sea ice patterns and thickness. This is also of importance for future Arctic shipping.

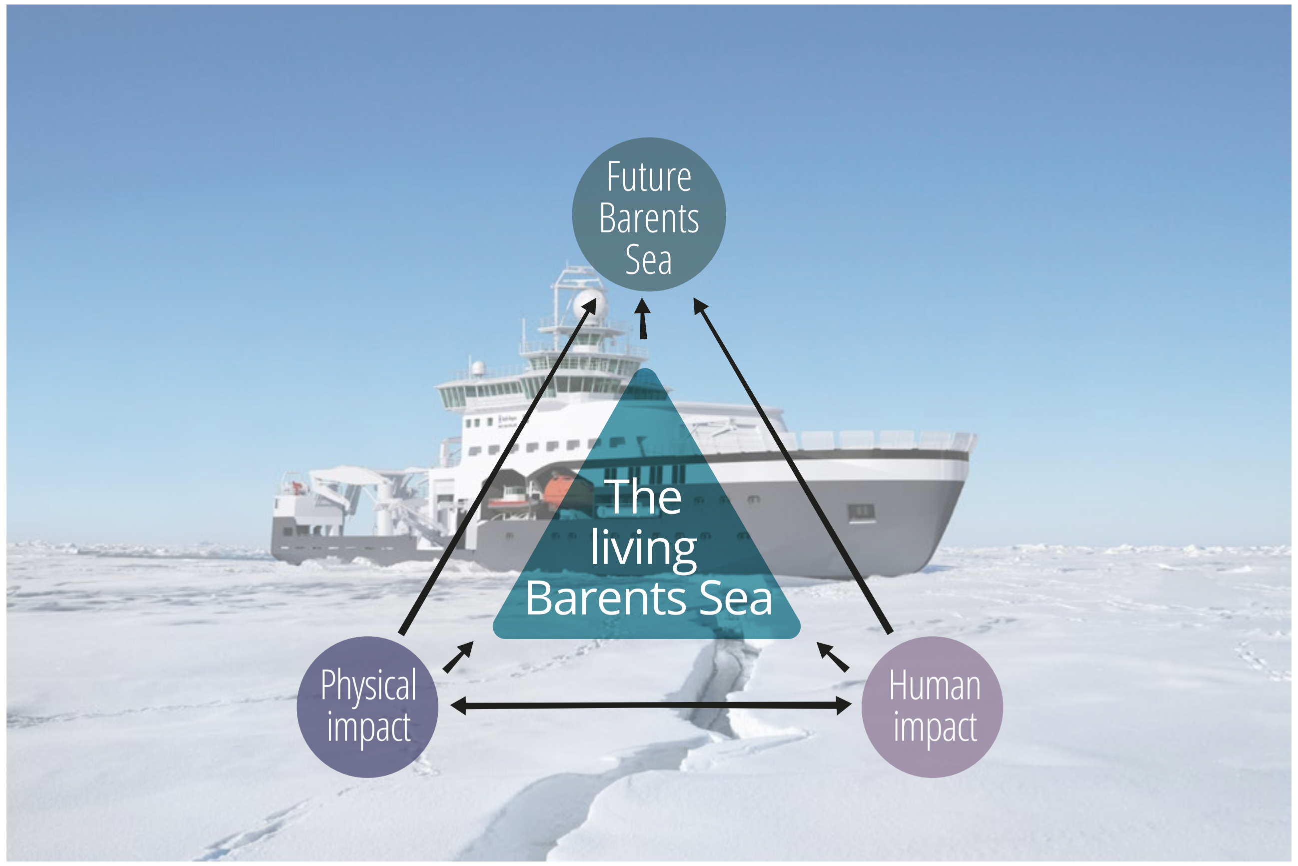
To strengthen the integration of results across the research foci of the Nansen Legacy, seven overarching key themes were identified, and dedicated task force groups have taken responsibility to develop products suited for different user needs. Synthesis and integration represent a more comprehensive step up from the primary publications. In parallel, a large group of Ph.D. students are summing up their results in their final year. Finally, the task forces focusing on seasonality is currently compiling a special issue that includes many of the studies from the seasonal research cruises conducted in 2019 and 2021.

Post doctoral researchers have made invaluable contributions to the project. Several contracts ended in 2022 and many have moved onto permanent research positions, new post docs, or jobs outside academia. Fourteen master students have been matriculated. The first Nansen Legacy Ph.D. candidate, Elliot Sivel, achieved his degree in April 2022 with many more to follow.

Various arrangements were used to communicate our results and new knowledge widely. During the Arendalsuka, the One Ocean Summit, Nor-Fishing, and Arctic Frontiers, we had debates and dialogs with users and policy makers. During the national research days, Forsker Grand Prix, and through media, we reached out to children, students, and the wider general public.

In the final phase of the project, our focus is on integration and making the results visible, useful, and accessible. That also includes all the data that has been collected and produced. This way our innovative voyage of a research project equivalent to a research program can create a knowledge base and prove its legacy. ■

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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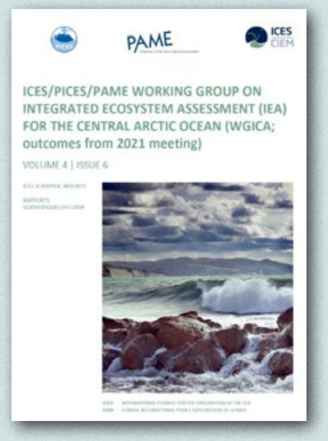
Photo: Olaf Schneider

2022 in brief

Arctic Frontiers side event: During Arctic Frontiers the side event “From Science to Policy,” a discussion on useful Arctic science engaged both the Nansen Legacy early career scientists and the minister of climate and environment.

The winter gap cruise: The interdisciplinary cruise on *RV Kronprins Haakon* aimed to close knowledge gaps in the Arctic winter-spring transition period.

Synthesis workshop - The seafloor habitat: An interdisciplinary group of Nansen Legacy researchers with data and interest in the sea floor met to discuss sediment properties, biota, processes and contaminants.



Ecosystem Assessment of the Central Arctic Ocean: Five Nansen Legacy scientists contributed to the joint ICES-PAME-PICES assessment describing the Ecosystem in the Central Arctic Ocean (ICES, WGIAO).

Winter

Spring

One Ocean Summit Brest: The Nansen Legacy reported from a workshop on the Polar Oceans that called for a strong international collaboration to reduce climate change and secure biodiversity and habitats.

YouTube data management: Our data manager Luke Marsden has created excellent YouTube videos to guide our (and other) scientists through the many steps to reach FAIR data handling. Search for Nansen Legacy in YouTube to find them.

Ph.D. course – Illustrate your science: Informative scientific illustrations are often key in the communication of research. A graphical communicator introduced visual and hands-on methods and guided the process to a graphic product in a well-attended workshop.

Arendalsuke & Nor-Fishing: The Nansen Legacy discussed the vulnerability of the seasonal ice zone and the Ocean decade challenges with politicians, stakeholders and industry gathered in Arendal and in Trondheim.

DarwinCore workshop: Standardisation of biological data for archiving and sharing is new knowledge for many biologists. The workshop provided guidance and time to archive Nansen Legacy biological data in a FAIR way.

Mooring service cruise Since 2018, sensors on moorings have provided us with full-year measurements on environment and biology in the seasonally ice-covered northern Barents Sea. New calibrated sensors with full batteries and empty storage space replace the old ones and data are brought home.

Early career writing retreat: A week on Sommarøy gave time for the early careers to focus on writing papers. More experienced post docs shared tips with Ph.D.s in their morning and afternoon briefs.

Fish population cruise: To get an overview of sub-populations of the polar cod and capelin, the fish collection from earlier years were complemented with fish collected at the southern and western part of Svalbard.

Summer

Autumn

Polar Front cruise: Finalising the seasonal investigation of physical processes taking place in the Polar Front region where the warmer southwestern Barents Sea meets the cold Arctic northern Barents Sea.

Sea ice workshop: Discussion on and overview of sea ice data and results across disciplines and approaches helped to build a common platform for discussions and interpretation of results.

Annual meeting/ Recruit Forum: In 2022 the Nansen Legacy Annual meeting and the Recruit Forum took place in Bergen. A focus on results and integration also involved user groups and end products.

Food web session: A small delegation of the Nansen Legacy early career researchers organised a successful session on food webs in a changing Arctic during the Canadian Arctic Net conference in Toronto.

Photo: Olaf Schneider

Increased marine heatwave frequency in the Barents Sea and their ecological implications

In June and July 2022, heatwaves were widespread in Europe, North Africa, and Asia with temperatures above 40° C. Similar to the heatwaves we have seen on land, heatwaves also occur in the ocean. The heatwaves in the Barents Sea have increased in both frequency and duration during the past years, with impact on ecosystems and fish populations. Nansen Legacy scientists have investigated the still little understood marine heatwaves and found new details on their occurrence and impact.

Marine heatwaves - more often, longer, and more intense

As on land, marine heatwaves are short periods of abnormally high temperatures in a particular region, and they come on top of the general global trend of ocean warming. A recent IPCC Special Report on the Ocean and Cryosphere found that marine heatwaves have doubled in frequency since 1982, but studies on marine heatwaves in the Arctic, and especially in the Barents Sea – the epicenter of Arctic warming – are rare.

Using daily high-resolution satellite data of sea-surface temperature, Nansen Legacy scientists investigated the occurrence of marine heatwaves in the Barents Sea. They identified 72 marine heatwaves in the Barents Sea between 1982 and 2020. Of these, 54 took place after 2003. Hence, marine heatwaves have become substantially more frequent in the Barents Sea in the last two decades. Further, the increase in frequency of marine heat waves is twice as high as the global average. Marine heatwaves in the Barents Sea have also become longer-lived and more extreme with respect to water temperature. The heatwave frequency, duration and intensity differ across the Barents Sea. While the seasonally ice-covered northern Barents Sea is exposed to relatively many heatwaves with short duration, heatwaves tend to last longer and are more intense in the southern ice-free Barents Sea.

Two hundred days with heatwaves in 2016

During 2016, 200 of the 365 days were affected by seven marine heatwaves in the Barents Sea. The most intense heatwave started in the southern Barents Sea on 28 June and spread northwards for 63 days into the northern Barents Sea. At its maximum, sea surface temperatures were more than 4˚C above the seasonal average water temperature. Nansen Legacy scientists found that fish shifted their geographic distribution during this heat wave. Cod and herring mainly migrated towards the east, while capelin moved northward. Polar cod nearly disappeared from its core area in the southeastern Barents Sea.

Different responses of fish to marine heatwaves

The marine heatwaves may have far-reaching consequences on marine animals and the ecosystem. A complementary Nansen Legacy study of the ecosystem response revealed that the response of single species, populations, and food web structure is not similar each time a heatwave occurs. While some heatwaves led to geographical redistribution of whole fish communities in the Barents Sea, other heatwaves only triggered the geographical expansions of single species. Marine heatwaves thus complicate the predictions of species geographical distribution in the generally warming Barents Sea and Arctic Ocean making future sustainable management of these regions more difficult. ■

> "The rate of increase in marine heatwave frequency in the Barents Sea is double the global average, making the Barents Sea a high-risk region for the ecological impact of marine heatwaves."

Bayoumy Mohamed, UNIS

References:

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Husson B, Lind S, Fossheim M, Kato-Solvang H, Skern-Mauritzen M, Pécuchet L, **Ingvaldsen RB**, Dolgov AV, Primicerio R (2022) Successive extreme climatic events lead to immediate, large-scale, and diverse responses from fish in the Arctic. *Global Change Biology* 28: 3728– 3744.

Mohamed B, Nilsen F, Skogseth R (2022) Marine heatwaves characteristics in the Barents Sea based on high resolution satellite data (1982–2020). *Frontiers in Marine Science* 9.

Photo: Christian Morel/christianmorel.net

Response to crude oil varies for Arctic zooplankton and fish

The shipping and petroleum industries foresee new business opportunities in the future Arctic, which could provoke accidental oil spills in an area that experiences extreme environmental conditions. Petroleum compounds decompose slowly in cold climates, and low concentrations may persist in the marine environment for a long time. The effects of these low and not immediately deadly concentrations were investigated by Nansen Legacy scientists.

Very low concentrations of crude oil components affect zooplankton

In the North Atlantic and the European Arctic, three sibling species of zooplankton are frequently found. They belong to the genus Calanus, but they vary in size from 2.5 to 7 mm. *Calanus finmarchicus* is the smallest, *Calanus glacialis* has an intermediate size, and *Calanus hyperboreus* is the largest. All three sibling species play an essential role in the Arctic food web, because they graze on algae while they themselves are important prey for fish and sea birds.

Thus, it is essential to know how these key species in the food web react to very low concentrations of crude oil in the Arctic. Researchers found that the cells of the two smaller siblings *Calanus finmarchicus* and *Calanus glacialis* responded similarly. The studied species began the production of detoxification enzymes to clean themselves of the crude oil toxicants. The larger *Calanus hyperboreus* initiated a variety of detoxification processes and its reaction to the toxicants was much more comprehensive when compared to the other two species. Their findings suggest that *Calanus hyperboreus*, the true Arctic species with the higher percentage of body fat, may be more sensitive to crude oil exposure than its slimmer sibling species.

Polar cod exposed to low levels of crude oil through their diet

In another experiment, Nansen Legacy scientists investigated if and how polar cod (*Boreogadus saida*) is affected when feeding on crude oil-contaminated zooplankton for more than 8 months. Neither the survival nor fish growth was considerably affected by the chronic exposure to low levels of petroleum compounds through its prey. However, the composition of fat in the cod's liver differed in exposed fish, suggesting that more energy was needed for detoxification processes.

A robust ecosystem – even after a potential oil spill?

These conducted experiments suggest that both zooplankton and fish are relatively robust against exposure to very low and not immediately deadly concentrations of crude oil. Human activities in the Arctic must still be conducted with utmost caution because the experiments also demonstrated that true Arctic species, such as the zooplankton *Calanus hyperboreus,* may be more sensitive to crude oil exposure than its Atlantic siblings. This may result in yet unknown effects on zooplankton reproduction and population dynamics, considering that changing sea ice cover and a warmer Arctic has caused a shift in prey community composition. ■

> "Our exposure levels caused sublethal effects on the lipid composition of liver tissue after 8 months, presumably indicating an altered allocation of energy upon exposure."

Ireen Vieweg, UiT

References:

Vieweg I, Bender ML, Semenchuk PR, **Hop H**, **Nahrgang J** (2022) Effects of chronic crude oil exposure on the fitness of polar cod (*Boreogadus saida*) through changes in growth, energy reserves and survival. *Marine Environmental Research* 174: 105545.

Yadetie F, Brun NR, **Giebichenstein J,** Dmoch K, **Hylland K, Borgå K, Karlsen OA, Goksøyr A** (2022) Transcriptome responses in copepods *Calanus finmarchicus*, *Calanus glacialis* and *Calanus hyperboreus* exposed to phenanthrene and benzo[a]pyrene. Marine Genomics 65: 100981.

Photo: Åström, Bluhm, Rasmussen 2022

Methane seeps diversify diets of Arctic organisms living on the seafloor

While the sun is the prime energy source for aquatic life through algal photosynthesis, release of methane from the Barents Sea seafloor may represent a more important supplementary energy source for nearby seafloor communities than previously assumed.

Natural releases of methane gas create specialized ecosystems on the seafloor

Methane gas, trapped deep within the Earth's crust, can leak from cracks found at the sea floor. These cracks, better known as methane/cold seeps, are found all over the world's ocean, including the polar regions. Methane seeps release carbon from the sea floor also within the Arctic Ocean, but the utilization of this carbon source by sea floor organisms has been largely unknown. At these sites, a process called chemosynthesis (where microbial complexes can assimilate energy from chemical compounds released at the seeps) can serve as an alternative energy source for specialized benthic organisms in the sea. This energy flow represents another potential food source for organisms who live far away from sunlight and photosynthetic energy.

The role of methane seeps in Barents Sea benthic food webs

Similar to other Arctic areas, benthic communities on the Barents Sea shelf (average depth 230 m) are seasonally reliant on the food supply from the overlying water column. Food supply comes in the form of falling organic matter from the surface such as sea ice microalgae and phytoplankton. While chemosynthetic carbon contributions are more apparent in deep sea systems, such trophic interactions are less known for shallower, highly productive Arctic shelves. Emmelie Åström, a VISTA program (by the Norwegian Academy for Science and Letters) and Nansen Legacy post doctorate, and her fellow UiT The Arctic University of Norway colleagues have now documented that chemosynthetic carbon sources were a complementary food source for some benthic organisms and diversified the diet to the seafloor community at Barents Sea seeps.

Their findings supported previous cold seeps research, in that many benthic organisms (including those who do not specialize in the incorporation of chemosynthetic carbon) can utilize the additional carbon source found at methane seeps. But they also demonstrate that this also occurs within productive Arctic shelves, where the photosynthetic production is high. Even though many organisms were still found to utilize photosynthetic carbon, this study highlights the diverse diets of benthic taxa in a seasonally variable Arctic environment. It is likely that the use of chemosynthesis-based carbon in benthic taxa is more common than previously thought, as new methane seeps are gradually discovered through Arctic explorations. ■

"The fact that food derived from chemosynthesis not only occurs in isolated deep-sea habitats with limited support from photosynthesis but is also found in highly productive Arctic waters highlights the various effects of cold seeps."

Emmelie Åström, UiT

Reference:
Åström EKL, Bluhm BA, Rasmussen TL (2022) Chemosynthetic and photosynthetic trophic support from cold seeps in Arctic benthic communities. *Frontiers in Marine Science* 1457.

Photo: Christian Morel/christianmorel.net

Capelin or not? Nonlinearity explains cod population dynamics

Ecosystem based management includes not only the species of interest, but also strong interactions with other species and the environment. For management it is therefore important to know how change in capelin stocks impact the northeast Arctic cod in the Barents Sea – and if the impact is straightforward (linear), or not proportional (non-linear).

Linear and nonlinear species interactions within populations

The study of population dynamics explores how population size varies from biological (changes in demographic rates) and environmental (changes in climate) effects. Interaction between species, such as competition or predation, is another important factor affecting population dynamics. In the Barents Sea, capelin (*Mallotus villosus*) and northeast Arctic cod (*Gadus morhua*) are two iconic fish species whose populations interact, and thus affect each other's population. Cod preys on capelin, controlling capelin abundance. Irregular abundance of capelin is thought to affect cod dynamics. Both fish population dynamics are also affected by fishing and the indirect effect of climate change.

In this predator-prey system, an example of a linear effect would be when cod eat capelin, causing the population decline of capelin. However, cod and capelin are found in a dynamic marine environment which has experienced shifting species distributions and altered food web dynamics. These examples are complex and interwoven through many ecosystem processes and can result in nonlinear effects of species interactions. This study explored whether the interaction between cod and capelin was linear or nonlinear, and to better understand nonlinear population dynamics as it related to trophic interactions within the Barents Sea ecosystem.

Historical data reveal non-linearity

Nansen Legacy researchers applied a Gompertz state-space model (a stochastic model for time series observations of population abundances) on historic data that comprised over 37 years of capelin and cod survey data. Our researchers demonstrated that capelin is beneficial for the cod population only at high capelin abundance. Below a certain threshold amount of capelin, the cod is not affected by capelin abundances. Their results indicate that the effects of capelin on cod are not linear but shifts depending on capelin abundance. This result is supported by the fact that cod is a generalist predator whose diet follows the community composition changes within the Barents Sea food web.

Our researchers' findings demonstrate the importance of investigating nonlinearity in species interaction models, and how this affects the overall understanding of food web functioning. This analysis contributes to an improved understanding of species assemblages and is of importance for ecosystem based and sustainable management. ■

"To be prepared for climate change we must challenge ourselves by accepting that hard acquired knowledge on ecosystem and trophic interactions may no longer be accurate and not reliable for prediction."

Joël Durant, UiO

Reference:
Durant JM, Ono K, **Langangen O** (2022) Empirical evidence of nonlinearity in bottom up effect in a marine predator-prey system. *Biology Letters* 18: 20220309.

Photo: Christian Morel/christianmorel.net

Smaller, cheaper, and open source: Studying the ocean with new technologies

Imagine opening a box of a 1000-piece puzzle, but the box only contains a few pieces. Would you still be able to understand the complete picture? Arctic scientists face exactly that challenge. They collect data that represent snapshots in time and space, making the picture far from complete. Increased use of remote and autonomous platforms and new combinations of these can extend our observations in time and space to gain a more comprehensive picture of the ocean.

Using a torpedo-like instrument for turbulence measurements

Autonomous underwater vehicles (AUVs) resemble submarine torpedoes but with a very different purpose. AUVs are equipped with many sensors that collect observations in the ocean, while diving and moving in the water independently of pilots and research vessels. During a Nansen Legacy cruise, a rather small AUV (35 kg, 2.6 m long) with open-access software was deployed to test if it could collect turbulence data, just like the larger and more expensive AUVs. These data help to understand mixing between different water masses and its implications for the ecosystem. Test dives of this smaller AUV showed that vibrations from the AUV itself obscured turbulence measurements in low turbulent environments. However, in high turbulent environments, the AUV provided good measurements, allowing the scientists to quantify ocean mixing.

Waves in an ocean with sea-ice

To improve large-scale wave and ice models that are important tools to predict future climate scenarios, improved mathematical descriptions of the dynamic interactions between sea ice and waves are needed. The key challenge is the lack of actual wave measurements in very different types of sea ice. Nansen Legacy scientists and their international colleagues have now developed the OpenMetBuoy, an inexpensive, easy-to-build open-source instrument to place on the sea ice to collect more data under different wave conditions. This was successfully deployed during Nansen Legacy cruises in 2021 and 2022.

Collecting color fingerprints of algae

Remotely operated vehicles (ROVs) are underwater robots that are connected to the surface via a cable. In Kongsfjorden in Svalbard, Nansen Legacy researchers tested a new setup consisting of two commercially available mini ROVs carrying an Underwater Hyperspectral Imager. The imager is a highly advanced camera that can capture more information on color than a normal camera. While a normal camera uses red, green, and blue to make an image, the underwater hyperspectral imager collects information covering the visible color spectrum. This allows for an "optical fingerprint" of objects. Comparing images taken with the mini-ROV to a library of "optical fingerprints" of seaweeds, scientists were able to map and identify the different macroalgae in Kongsfjorden without using scuba divers or big and expensive ROVs. ■

"The relatively small size and weight of this ROV [...] may reduce the user threshold and cost for mapping of seafloor and facilitate the logistics for field work in remote areas."

Natalie Summers, NTNU

References:

Kolås EH, Mo-Bjørkelund T, Fer I (2022) Technical note: Turbulence measurements from a light autonomous underwater vehicle. ***Ocean Science*** 18: 389-400.

Rabault J, Nose T, Hope G, **Müller M**, **Breivik Ø**, et al. (2022) OpenMetBuoy-v2021: An easy-to-build, affordable, customizable, open-source instrument for oceanographic measurements of drift and waves in sea ice and the open ocean. ***Geosciences*** 12: 110.

Summers N, Johnsen G, Mogstad A, Løvås H, Fragoso G, **Berge J** (2022) Underwater hyperspectral imaging of Arctic macroalgal habitats during the Polar Night using a novel Mini-ROV-UHI portable system. ***Remote Sensing*** 14: 1325.

Photo: Christian Morel/christianmorel.net

A new rheology provides excellent representation of sea ice movement

Like rock and glass, sea ice cracks, resulting in leads, ridges, and new frozen areas. These features are important for both the exchange of heat and CO_2 between the ocean and atmosphere, but also the light environment under the sea ice, as well as improving sea ice forecasts for shipping routes. The sea ice descriptions in climate models have so far not been good enough, but a new way of describing sea ice in models opens new possibilities.

The drift and deformation of sea ice

Polar ice caps are dynamic entities, growing and shrinking annually. Sea ice is also affected by the atmosphere and ocean, where strong winds move and break ice floes and warmer water temperatures can melt sea ice from below. How sea ice movement reacts to wind and ocean currents can be simulated in mathematical models. In such models, this reaction is simulated with various equations that are collectively referred to as rheology. Rheology, the science of flow and deformation of matter, describes the relationships between force, deformation, and time. This terminology is derived from the Greek *rheos*, meaning "to flow," and *logia*, which means "the study of."

Nansen Legacy scientists present a new method

In this study, scientists developed a new brittle Bingham-Maxwell rheology with a new numerical implementation. The new rheology extends an earlier version the researchers created (Maxwell-Elasto-Brittle rheology) and used in previous versions of their sea ice model. While the previous version resulted in good descriptions of how sea ice reacts to winds and currents, the scientists were faced with two concerns. The sea ice in the model would become unrealistically thick after several modelled years, and the model required a lot of computer time to run. The new rheology, hence, is an updated rheology with the inclusion of an extra mathematical term. Modelled results prevent the excessive piling up of ice. Scientists also proposed a more efficient way for solving the equations within the models.

A realistic representation

Scientists found that the new brittle Bingham-Maxwell rheology provided a good distribution of the magnitude of sea ice deformation and a better temporal variability of where the highest deformation rates could occur. The maps from their rheology were very realistic in their outputs, even down to localized features. This study shows that this new rheology can better simulate realistic spatial ice thickness as well as its temporal evolution. Finally, the new rheology allowed for better modelled simulations of how sea ice moves on a daily basis, when compared to satellite observations. ■

"With this latest work, we now understand the processes better and have a powerful new tool to address the questions we initially posed. This is emblematic of cutting-edge research, where you think you understand what is happening, only to be proven wrong by your next result. It's this constant discovery that makes the work so fascinating!"

Einar Ólason, NERSC

Reference:

Ólason E, Boutin G, Korosov A, Rampal P, **Williams T,** Kimmritz M, Dansereau V, Samaké A (2022) A new brittle rheology and numerical framework for large-scale sea-ice models. *Journal of Advances in Modeling Earth Systems* 14.

Glimpses of the Nansen Legacy knowledge production

The Nansen Legacy team generates new and holistic understanding of the northern Barents Sea climate and ecosystem. Over the past years, the team has delivered many peer-reviewed articles in leading scientific journals. These studies are all pieces of the larger puzzle. Here we present glimpses of last year's knowledge production.

The living Barents Sea

- Core populations of the Arctic *Calanus hyperboreus* in the Norwegian Seas were found to originate from the Greenland Sea. **Low *C. hyperboreus* abundances in the Norwegian Sea are more likely controlled by predation**. Aarflot et al. 2022
- **Comparison of trophic position estimates from field based stable isotope data and an Ecopath mass-balance food web model showed good agreement** for the species found in the Barents Sea. Pedersen 2022
- **Ecosystem response to several heat waves included** both **redistribution of fish communities** on the scale of the entire Barents Sea and more local responses on the species level. Varied ecosystem responses to similar events make predictions more challenging. Husson et al. 2022
- Year-round measurements of sinking organic matter in areas with and without winter sea ice to the west and east of Svalbard found that **ungrazed algal fluxes were higher in the eastern areas with sea ice presence due to less zooplankton grazers**. Dybwad et al. 2022
- Megabenthic species composition and functional traits found that **boundaries between water masses and depths are associated with both gradual taxonomic and sharp functional transitions of benthic fauna**. Jørgensen et al. 2022
- Strong niche partitioning limited competition between ten marine mammal species in the European Arctic. **The marine mammal species differed in how they feed on pelagic, benthic, and planktonic/algal carbon sources**. MacKenzie et al. 2022

Hydrography and sea ice

- For the first time, **heat loss from the Atlantic Water in the region north of Svalbard was measured over an entire year**. Larger heat loss from the Atlantic Water inflow during eastward transport in winter than spring. Koenig et al. 2022
- **Throughout the last century, Atlantic water volume and heat transport has increased consistent with increased wind forcing and heat loss**. Anomalies in ocean heat transport affected the loss of Arctic sea ice, the retreat of marine terminating glaciers in Greenland, and an increase of CO_2 uptake in the Arctic Ocean. Smedsrud et al. 2022
- Two-year mooring records from the northern Barents Sea demonstrate **stronger and warmer inflow from the north during autumn and early winter. The import of sea ice into the Barents Sea has a long-lasting impact on the upper ocean**. Lundesgaard et al. 2022
- **The interannual variability in winter sea ice concentration of the Barents Sea** over the last 40 years **is explained by areal change as well as the redistribution of sea ice** due to anomalous wind and sea ice imports. Efstathiou et al. 2022
- **Results from a hindcast ocean model simulation demonstrated** decreased stratification over most Arctic shelves and the Transpolar drift from the 1970 to 2019. These changes were explained by **altered wind stress and freshwater supply**. Hordoir et al. 2022
- **Wind events** from passing weather systems from south-west **can explain much of the short time variability** in the Atlantic Water current along the Norwegian coast and towards the Barents Sea. Brown et al. 2022.

Pollution, warming, and ocean acidification

- The main driver of **pH drop in the Nordic Seas** from preindustrial times to 2100 was the **increase in dissolved inorganic carbon,** caused by the raising of anthropogenic CO_2. Frasner et al. 2022
- Two reviews focus on **multiple stressors and how climate change is impacting the long-range transport of pollutants into the Arctic.** Impact of persistent organic pollutants is altered by atmospheric, environmental, and ecological processes, often synergistically. Borgå et al. 2022, Dinh et al. 2022
- A coupled model intercomparison project phase 6 scenario shows the **upper 2000 m of the Arctic Ocean warms at 2.3 times the global mean rate**. Arctic Ocean Amplification of both the ocean and atmosphere indicates the Arctic is one of the Earth's regions most susceptible to climate change. Shu et al. 2022
- **Average mercury concentrations** were found in surface marine sediments in the northern Barents Sea, with higher concentrations in the deep Eurasian Basin. Concentrations **were lower and less variable during the polar night compared to summer.** Kohler et al. 2022 a, b
- A review on **light pollution during the polar night** shows how it masks navigation, both predation patterns and spawning synchronicity, as well as **inhibits zooplankton diel vertical migration.** Marangoni et al. 2022

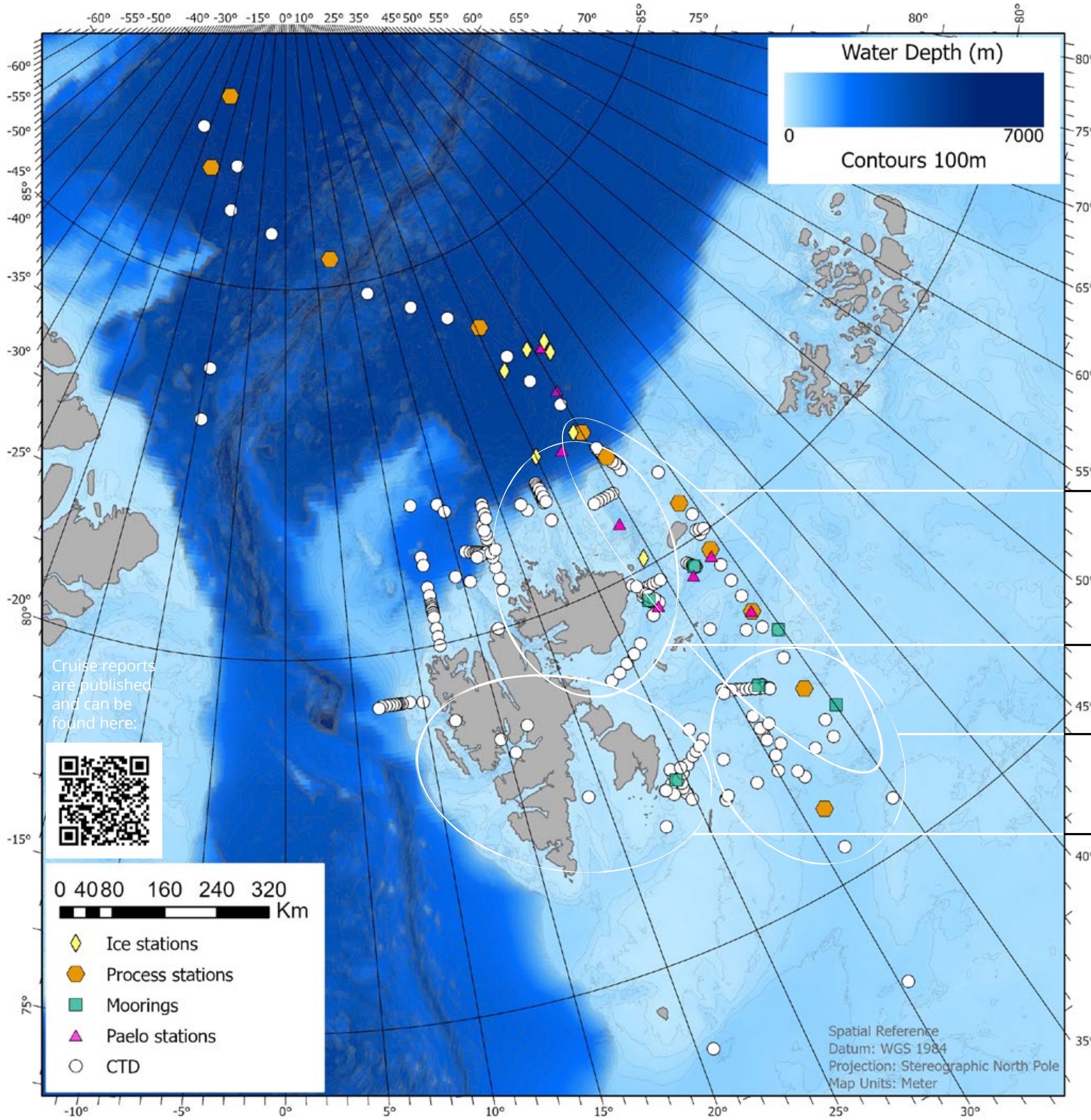
Technology and Method Development

- **Water quality monitoring applications is improved** with a spectral harmonization method for the Landsat-8 operation land imager and Sentinel-2 multispectral instrument-derived remote sensing reflectance products. Asim et al. 2022
- A novel method incorporating machine learning techniques to **classify hyper- and multi-spectral observations into optical water types** was developed and is ready to be tested within the Arctic to improve operational processing and water type assessments. Blix et al. 2022
- The criteria for an **online risk model for autonomous marine systems** were identified. While the analysis was performed using an under-ice autonomous marine system as a case study, the developed criteria can be incorporated into future studies to assess the validity and effectiveness of other autonomous marine systems. Yang and Utne 2022
- A new technique **provides insights on how models can reproduce profiles within the upper-most ocean layer within different regions and seasons**. Combining a new unsupervised neural networking technique with traditional ocean model evaluations provides additional information on modelled vertical ocean temperature profiles. Thomas and Müller 2022
- The **OpenMetBuoy-v21** is an easy-to-build, open-source instrument for oceanographic **measurements of drift and waves in sea ice** and the open ocean that help improve weather forecasts. Rabault et al. 2022.

Photo: Christian Morel/christianmorel.net

The Nansen Legacy field campaigns finalized in 2022

In total, the Nansen Legacy has spent over one year at sea (386 days of ship time). These research cruises ensured data sampling at high-resolution and spanned the physical, chemical, and biological parameters of the northern Barents Sea and adjacent Arctic Ocean marine ecosystems. Technology development to enhance observational capacity has also been important. The project has now finalized the field-based work and completed a total of 21 research expeditions. The last four cruises were conducted in 2022.



MAP: J. Bilberry

RV Kronprins Haakon

Barents Sea transect
February 2 – March 11

Winter Gaps Joint Cruise 3

This cruise filled regional, temporal, and scientific gaps left behind from the earlier Nansen Legacy expeditions. In particular, it was important to reduce the knowledge gap of the winter-to-spring transition in the northern part of the Barents Sea transect into the Nansen Basin of the Arctic Ocean. Sampling periods at several longer-term process stations lasted from 29 to 68 hours in order to enable observations over one daily cycle in the under-ice water layer. Hydrographic and chemical sampling along the entire transect were carried out. This also included stations with biological and benthic sampling, as well as glider recoveries.

RV Kristine Bonnevie

Barents Sea Polar Front
September 28 – October 13

Polar Front Process Cruise

Polar front mixing processes using microstructure profiles and short-term moorings were in focus to understand connectivity between the southern and northern Barents Sea. The use of new technology, such as gilders equipped with turbulent sensors to further study polar front mixing on short-term missions was successful. Scientists collected physical process data at the polar front, on sub-tidal to synoptic timescales. Data from this cruise will be linked with data collected from previous expeditions, which will allow researchers to reveal the seasonal and inter-annual variability of the polar front.

RV Kronprins Haakon

Northern Barents Sea
October 2 – 11

Mooring Service Cruise

The Nansen Legacy and A-TWAIN projects again joined forces for another mooring cruise to secure the continuous data collection that has been ongoing since the project started. This cruise retrieved and redeployed moorings in the northwestern Barents Sea and on the continental slope north of Kvitøya. Hydrographic surveys in the areas of Atlantic Water inflow and other regions of interest were also conducted. Extensive hydrographic information was collected for mooring calibrations, as well as along a set transect. The cruise was able to assist other research objectives within the Nansen Legacy with the deployment and recovery of smaller equipment at various sites along the cruise track.

RV G.O Sars

Svalbard fjords
November 12 – 21

Polar Cod Connectivity Cruise

To compare populations studied along the Nansen Legacy transect east of Svalbard, this cruise aimed at investigating polar cod and capelin population connectivity in relation to both the physical and chemical environments in fjord regions west and south of Svalbard. The focus areas were Isfjorden, Kongsfjorden, Storfjorden, and the southeast region of Svalbard. Data on the vertical and horizonal distributions of polar cod and capelin was collected, as well as life history data for both fish species.This cruise facilitated additional sampling of physical processes during early winter, as well as collecting additional data on water chemistry as it relates to ocean acidification.

An overview of our data sampling methods

The Nansen Legacy researchers have collected an abundance of samples and data to gain more knowledge about the Barents Sea and Arctic Ocean. Here we show some of the different methods that have been used within the project.

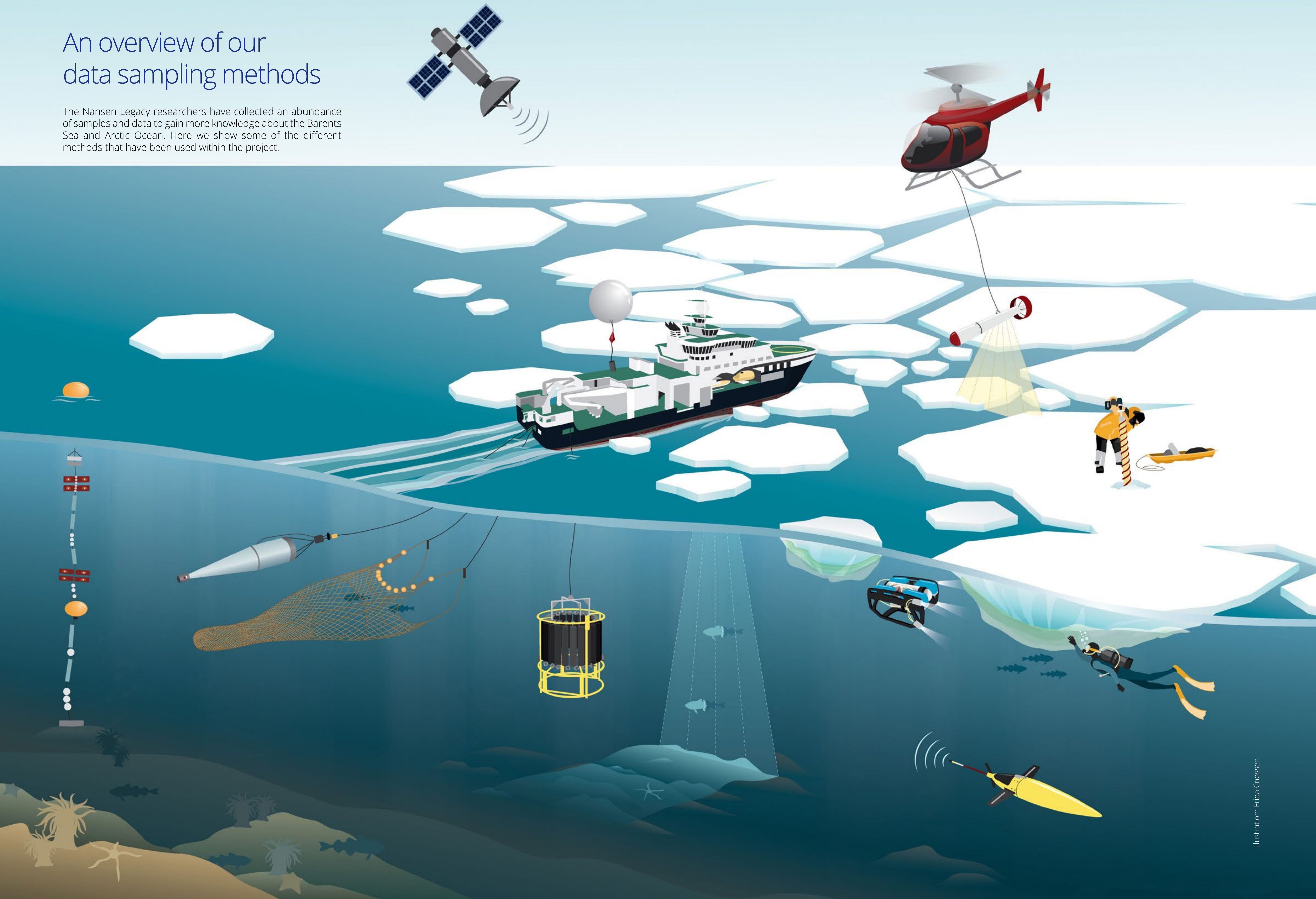


Illustration: Frida Cnossen

Sampling approaches and effort

A challenge in field sampling is to cover the temporal and spatial scales sufficiently to understand variability and how smaller and larger scale processes are connected. In the Nansen Legacy we have combined logistics and competence across partner institutions to optimize the observational capacity. We have used a combination of several moorings equipped with sensors that can monitor key variables throughout the year, complemented with different types of sampling events. Geological cores have provided data on long-term climate variability. Other ship-based sampling events have been dedicated to collecting samples and measuring processes and interactions along a spatial gradient from the open water, through the seasonally sea-ice covered shelf, and into the Arctic Basin. Ship-based events along with gilder deployments have explored processes like the mixing of water masses and heat exchange within the Polar Front region. Use of helicopters and/or autonomous underwater vehicles has also improved ship-based sampling and its spatial coverage. The temporal coverage and total efforts from some of these approaches is shown below.

Total sampling days

386 days at sea

16 days of helicopter flights

502 days of AuVs

13694 days of moorings

Joint sample collection and process studies

Interdisciplinary sampling of organisms ranging from viruses to fish in order to map biodiversity, measure production, or estimate food web connections were carried out on joint cruises. Sampling of the physical and chemical environment were conducted, including contaminant measurements and onboard experiments.

Helicopter with EM-bird

The electromagnetic (EM)-bird measures both sea-ice and snow thickness. The use of an EM-bird is complementary to detailed studies by sea ice physicists on the ice floes near the vessel, and satellite remote sensing. Weather permitting, the helicopter can cover larger areas and several ice floes and provides detailed observations that help map the spatial variations in sea ice thickness within the study region.

AUVs

Several types of AUVs were used during our field work, and gliders represent the most extensively used instrument. Gliders are deployed and retrieved by research vessels and can be operated for several months along pre-programmed transect lines, as well being remotely controlled by pilots on land. The gliders have been an important supplement to moorings by extending our spatial measurements.

Moorings

Moorings, equipped with sensors at different depths, provide continuous observations over several years and serve as our longest recorded datasets within Nansen Legacy. Sensors can measure hydrographic, chemical, and biological characteristics, respectively.

Evaluating food web models – why do we need standard protocols?

In a scientific context, a model is a fictitious representation of a system that is artificially constructed to help explore the nature of things within the system. Models can therefore be very different. It may be a simple drawing with arrows (Figure 1) or consist of complex equations that represent the multifaceted interplay between organisms within a food web (Figure 2). Until recently however, there was no standardized way to assess how good a certain model was suited to address a specific scientific problem, but Nansen Legacy scientist Benjamin Planque and his co-authors have now addressed this challenge.

- Benjamin, you and your co-authors have developed a standard protocol that allows the evaluation of ecological models. Can you provide a brief overview on why ecological models are an important tool for scientists, stakeholders, and policymakers?

Data are essential to describe ongoing changes in the Barents Sea ecosystem and to understand ecological processes. However, we cannot anticipate the consequences of management actions or of climate change from data alone. To explore possible futures or to make predictions about the consequences of our (in) action in the face of climate change or other drivers we need models. Ecological models allow us to integrate multiple sources of information and knowledge and use them to make informed predictions. For these reasons, models are essential to scientists, managers, and policymakers.

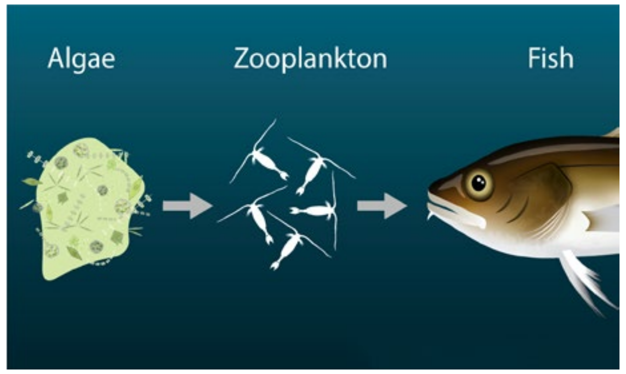


Figure 1: An illustrative example of a simplified model.
Illustration: Frida Cnossen

"Evaluating models is essential to determine what models are good at, and what they can be used for."

Benjamin Planque, IMR

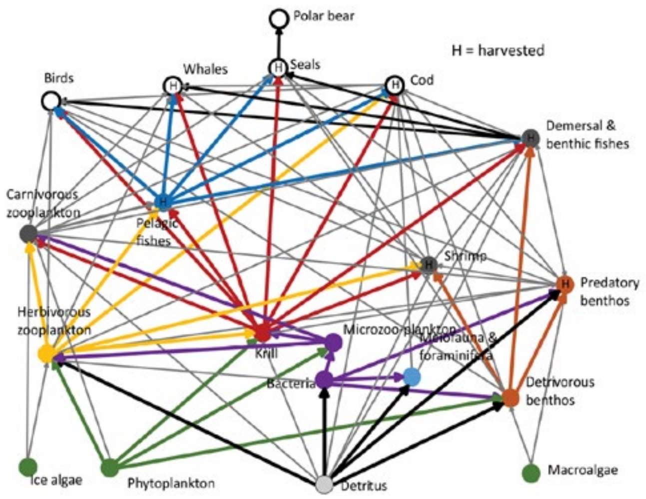


Figure 2: Example of a complex food web diagram, showing colored energy pathways within the Barents Sea ecosystem. Pedersen et al. 2021

- Why do you think ecological models should be evaluated?

Models are simplified representations of the real ocean, for example. They can be good at representing certain processes and less good at representing others. Evaluating models is essential to determine what models are good at, and what they can be used for. Model evaluation is not only desirable but essential, because without evaluation a numerical model is not much more than a mathematicised opinion, and one cannot tell how well-founded this opinion is.

- You and your co-authors have assembled a standard protocol to evaluate models. Can you briefly explain how the model evaluations work?

The protocol is grounded on three pillars: Objectives-Patterns-Evaluation. We call it the OPE protocol in reference to these three pillars. The first pillar deals with the motivation for building the ecological model, its projected use, and the expected outputs. For example, is the intention to use the model to explore the effect of ocean warming on biodiversity, is it to forecast multispecies biomass in coming years, or to explore the effects of increased shipping on the spatial distribution of marine mammals?

The second pillar is the description of the ecological patterns that are central to the question being addressed, and against which the model will be evaluated. These can be seasonal, spatial or interannual patterns of variation. They can be related to species biomass, biodiversity, trophic interactions, fishing opportunities, and so on. The third pillar is the numerical methodology used to evaluate the model against observations. To guide modellers through the evaluation, we have structure the protocol in 25 questions that can be answered sequentially.

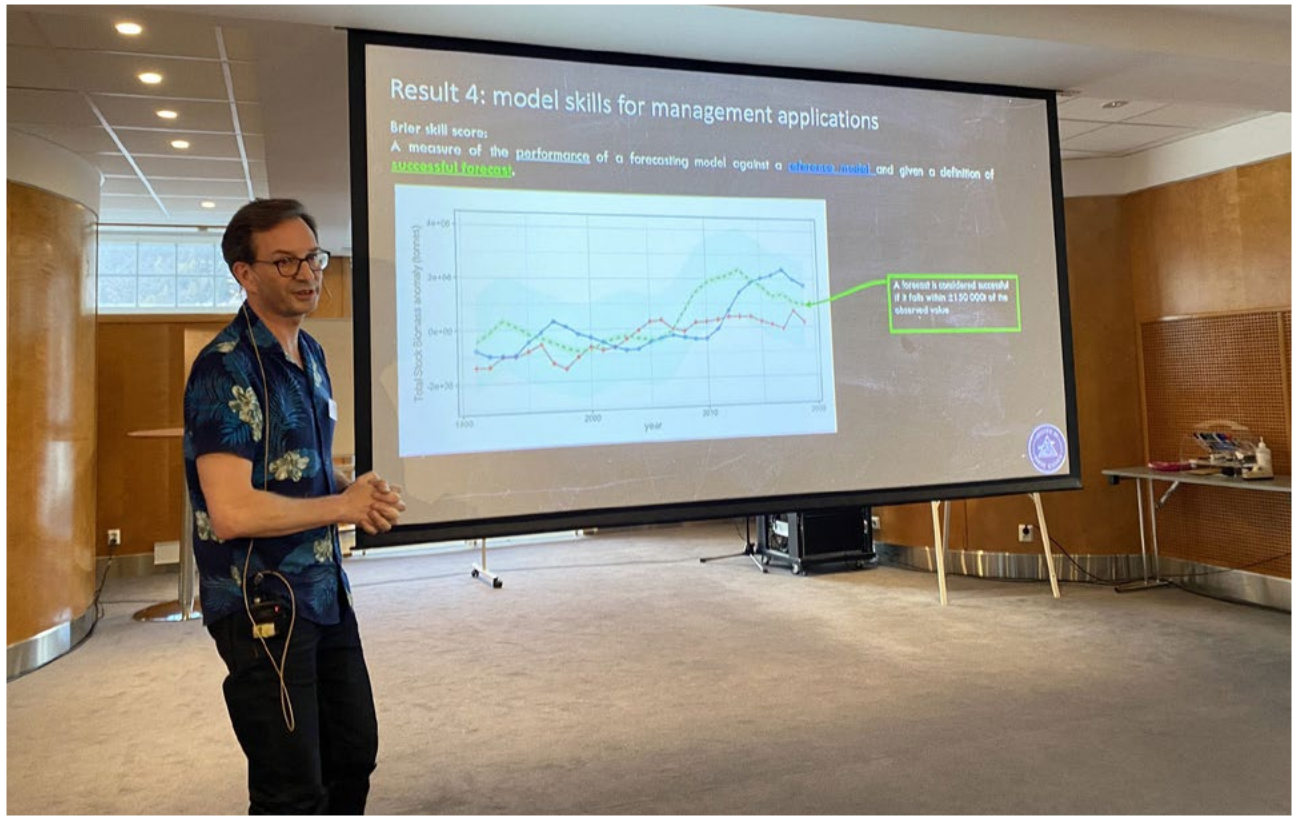
- Many Nansen Legacy scientists work with ecological models. Has your protocol already been used to evaluate these models and, if so, how did your protocol help to improve them?

The Nansen Legacy modelling community built the OPE protocol, and several of the models used in the project have been evaluated with this protocol. We found that the protocol is useful to standardise and increase the transparency of the model evaluation process. In addition, we found that going through the OPE protocol helps modellers to think more deeply about the purpose of their models. Going through the protocol helps clarify the objectives and exposes the performance of ecological models. For this reason, the OPE is also a tool that can support scientists when reviewing ecological modelling articles. We found it highly beneficial for modellers to consider the OPE early in the modelling process, in addition to using it as a reporting tool and as a reviewing tool.

- How do you think ecological models will develop in the future and what may they be able to tell us?

In the world of numerical modelling, a lot is happening, and the future is open. The role that Artificial Intelligence will play in the development of future ecosystem models is yet unknown but is likely to be transformative. Regardless of the new types of ecological models that will develop in the future, the usefulness of these models will be driven to a large extent by how much we believe the model outputs can tell us something about the real world. For this reason, model evaluation will remain central. Tools that help us to conduct objective evaluations of numerical models, and to report these in a transparent manner will be essential. ■

Reference:
Planque B, Aarflot JM, Buttay L, Carroll J, Fransner F, Hansen C, Husson B, Langangen Ø, Lindstrøm U, Pedersen T, Primicerio R, Sivel E, Skogen MD, Strombom E, Stige LC, Varpe Ø, Yoccoz NG (2022) A standard protocol for describing the evaluation of ecological models. *Ecological Modelling* 471: 110059.



Benjamin discussing the need to assess model forecast skills properly at the Nansen Legacy annual meeting.
Photo: Tor Eldevik, UiB

Using task forces to integrate results and highlight important themes

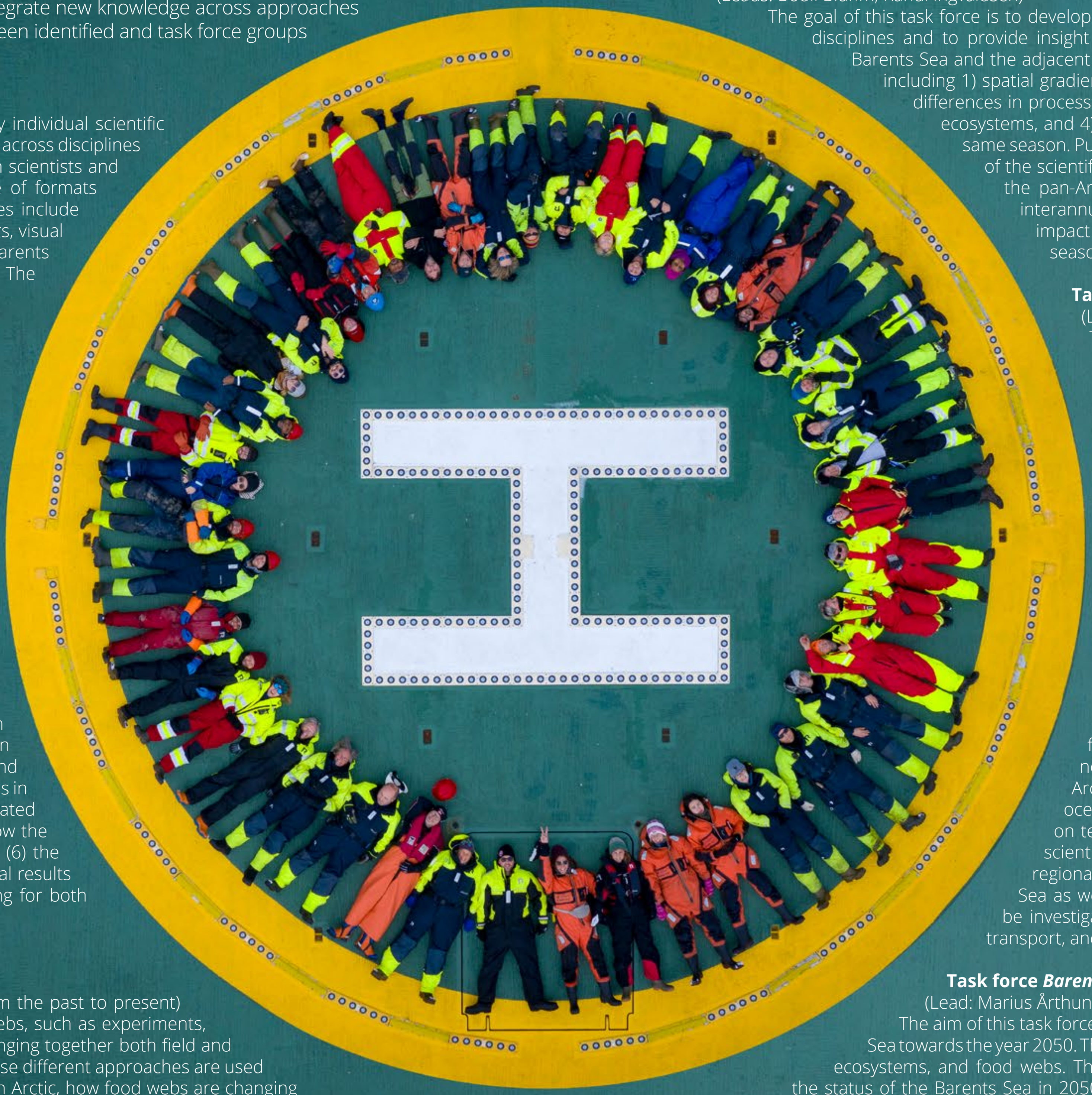
After a period with focus on data collection, sample analyses, and model-based investigations and predictions within the Nansen Legacy project, it is time to merge and integrate new knowledge across approaches and key themes. To do so, seven overarching themes have been identified and task force groups were initiated.

The task forces synthesise and highlight findings from the many individual scientific studies within the Nansen Legacy project in order to bridge results across disciplines and different scientific approaches. This includes workshops with scientists and user representatives. Results will be communicated in a range of formats for different audiences. Products developed from the task forces include synthesis articles in scientific journals, fact sheets for policymakers, visual presentations online, a new popular science book about the Barents Sea, and articles for publication in newspapers and magazines. The status of ambitions from the task forces are listed below.

Task force *Atlantic Water Inflow*
(Lead: Arild Sundfjord)
The aim of this task force is to summarise the new understanding of the factors affecting the flow of relatively warm, salty water originating from the Atlantic Ocean into the northern Barents Sea. This is achieved based on findings from observational and modelling studies of the ocean and sea ice conducted during the Nansen Legacy project. In addition, this task force seeks to provide a holistic understanding of the transport and redistribution of nutrients, carbon, plankton, contaminants, and pollution (including plastic) by currents in the Barents Sea and north of Svalbard.

Task force *Sea Ice*
(Lead: Sebastian Gerland)
This task force unites Nansen Legacy scientists with a background and/or interest in sea ice physics, sea ice biogeochemistry, nutrient dynamics related to sea ice, ice-ocean interaction, sea ice ecosystem, and sea ice modelling. Together, the scientists aim to improve the holistic understanding on (1) the light conditions in snow, ice, and water under the ice, (2) the processes of ice growth and melting, snow cover processes, (3) physical and biological processes in and near ridges, melt ponds, holes, cracks and leads, (4) brine-related processes and their effects on chemistry and biology in and below the sea ice, (5) the fluxes between atmosphere-snow-ice-water, and (6) the relevance of sea ice for society and teleconnections. Observational results are complemented with findings from sea ice modelling, allowing for both future projections and operational services.

Task force *Food Webs*
(Lead: Randi Ingvaldsen)
This task force investigates temporal changes of food webs (from the past to present) and aims to investigate different methods used to study food webs, such as experiments, trophic markers, and models. The scientists involved work on bringing together both field and observational findings with the results from food web models. These different approaches are used to gain a more integrated understanding of food webs in the high Arctic, how food webs are changing and may continue to change in the future.



Task force *Seasonality*
(Leads: Bodil Bluhm, Randi Ingvaldsen)
The goal of this task force is to develop a comprehensive understanding for seasonal processes across disciplines and to provide insight into the magnitude of seasonal variation within the northern Barents Sea and the adjacent Arctic Ocean. Results of process studies are currently compiled, including 1) spatial gradients in the sea ice, water column and at the seafloor, 2) seasonal differences in processes and biological communities, 3) interannual variability in Arctic ecosystems, and 4) the impact of differing ice regimes on an ecosystem during the same season. Publications on these topics are currently gathered in a special issue of the scientific journal Progress in Oceanography to communicate findings to the pan-Arctic scientific community. Further, the special issue addresses interannual comparisons within and across disciplines to evaluate the impact of differing ice regimes on the entire system during the same season.

Task force *Human Impacts*
(Lead: Khuong V. Dinh)
This task force works on providing an overview of the new findings on key abiotic and biotic drivers and stressors in the Arctic, such as findings related to ocean warming and acidification, altered nutrient input and oxygen content, sea ice loss and surface freshening as well as various types of pollution and harvesting. One of the goals is to integrate these findings with the seasonally and inter-annual changes of the drivers and stressors and to provide answers on how drivers and stressors interact and affect Arctic species and ecosystems on different time scales, from short-term (e.g., phenotypic plasticity) to long-term (e.g., natural populations, trophic interactions, and food web structures).

Task force *The Barents Sea: regional implications and global context*
(Lead: Camille Li)
Over the last century, large changes have been observed in the Barents Sea. There has been a loss of winter sea ice cover, the ocean has warmed, and the surface heat loss and uptake of CO_2 from the atmosphere has increased. Moreover, the Barents Sea is not an independent system. It is linked to adjacent regions in the Arctic as well as to the entire global climate system by the circulating ocean and atmosphere. This task force aims to integrate findings on teleconnections between the Barents Sea and other regions. The scientists involved will work towards an overall understanding of the regional implications of climate variability and change in the Barents Sea as well as this role in a global context. Important processes that will be investigated include sea ice import, water column stratification, energy transport, and modes of atmospheric variability.

Task force *Barents Sea 2050*
(Lead: Marius Årthun)
The aim of this task force is to summarize the projected changes in the (northern) Barents Sea towards the year 2050. This includes changes in the physical environment, biogeochemistry, ecosystems, and food webs. The main product of this task force will be a synthesis article on the status of the Barents Sea in 2050 as well as popular science products for different audiences. A workshop in November 2022 was held to plan on how the participating Nansen Legacy scientists will share the responsibilities in developing the planned synthesis products. ■

Photo: Christian Morel/christianmorel.net

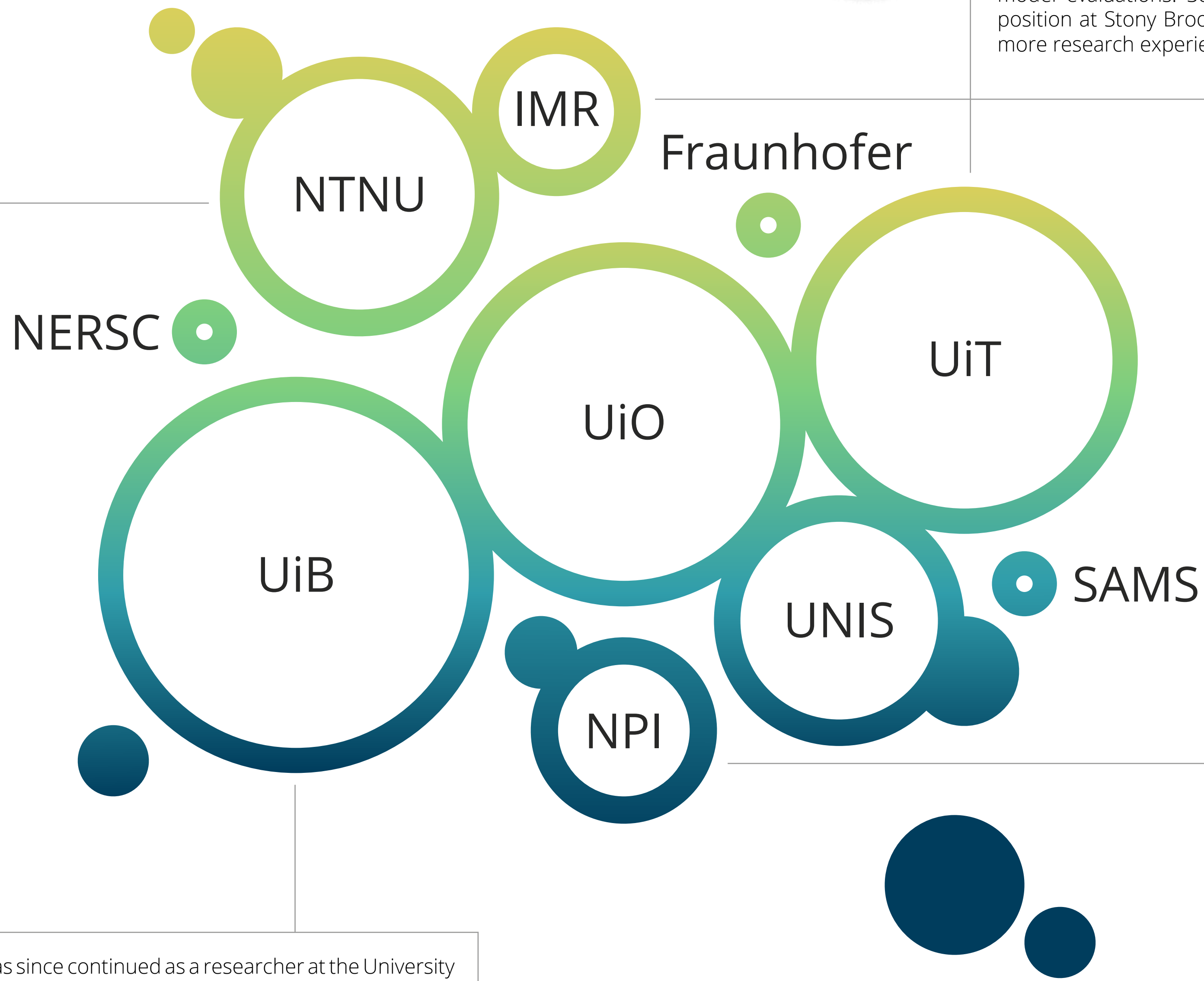
Photo: Angelika Renner

The Nansen Legacy as a second home

In 2022, The Nansen Legacy was home to over 60 early career scientists. These early career researchers are vital to the Nansen Legacy, as they add expertise and knowledge to the project and help connect the Nansen Legacy with other ongoing research efforts. The Nansen Legacy supports these early career scientists through the inclusion into a larger research community and with increased research opportunities.

Natalie Summers is a Ph.D. student at Norges teknisk-naturvitenskapelige universitet (NTNU) in Trondheim. She uses a combination of emerging technology and established laboratory techniques to map and monitor Arctic algal dynamics. One of the tools Natalie has been using is the Underwater Hyperspectral Imager and details on her scientific work can be found on page 12. Last autumn, Natalie stepped in for the teaching and organization of the graduate course in Enabling Technology for Marine Ecological and Marine Sciences studies at NTNU. One of the big challenges was organizing the one week of fieldwork, which includes logistics, administration, and safety aspects for all participants. Despite suddenly being exposed to new tasks, Natalie successfully filled the course leader position and ensured that students were able to complete the course.

Elliot Sivel defended his Ph.D. in 2022 from UiT The Arctic University of Norway. During his time at Nansen Legacy, he worked with food web models based on chance and necessity. His aim was to better understand the drivers of variability in natural systems. His research focused on identifying trophic control in the Barents Sea, and the combined effects of fishing mortality and temperature on the Barents Sea ecosystem stability. He worked with many other Nansen Legacy researchers in order to create best practices for ecological model evaluations. Soon after the completion of his Ph.D., Elliot accepted a Postdoc position at Stony Brook University (NY, USA). With his new position he continues to gain more research experience in ecological modelling, biostatistics, and marine biology.



Øyvind Lundesgaard is a Postdoc researcher at the Norwegian Polar Institute. After a Ph.D. at the University of Hawai'i, USA, he moved to Tromsø to study the ocean and sea ice in the northern Barents Sea and the Arctic Ocean. Øyvind's work in the Nansen Legacy project does not only involve scientific data and publications - in October 2022, he was the cruise leader of the Mooring Service Cruise, where he gained experience planning a research cruise and leading the science party onboard the *RV Kronprins Haakon*. The objective of the cruise was to retrieve and deploy moorings in the north-western Barents Sea and on the continental slope north of Kvitøya. The cruise was highly successful, and Øyvind and other Nansen Legacy researchers now have new and exciting mooring data from the ocean and sea ice.

Filippa Fransner completed her Postdoc in 2022 and has since continued as a researcher at the University of Bergen and the Bjerknes Center for Climate Research. Within Nansen Legacy, Filippa investigates the future biological production and chemical conditions within the Barents Sea, and how it is influenced by both climate variability and change. Her published findings on the acidification of the Nordic Seas identifies the major drivers of pH change in these water bodies and will be essential for their continued management. In another collaborative study, currently under review, she and an interdisciplinary group of scientists demonstrate that variations in the phytoplankton abundance can be predicted five years ahead in the Barents Sea (with the Norwegian Climate Prediction Model).

Center graphic: early career scientists (MSc students, Ph.D. students, Post doctoral fellows, and affiliate Ph.D. and PD members) involved in the Nansen Legacy project per institution. The size of the white bubbles corresponds to the number of early career students involved.

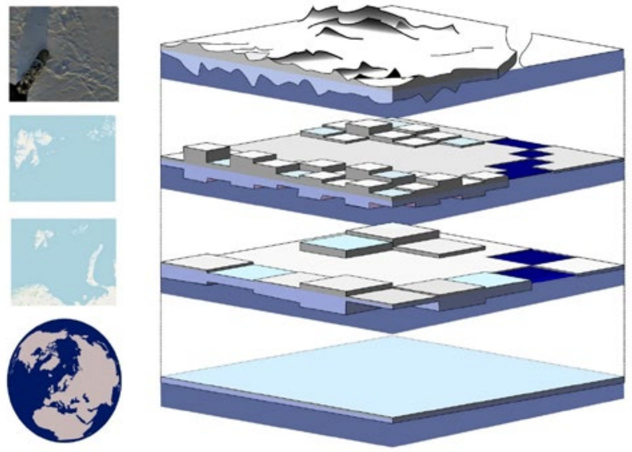
Graphical design skills for young scientists

Graphical abstracts, infographics, and one-slide posters for digital conferences – scientific results are increasingly communicated visually, often requiring design and illustration skills. The Nansen Legacy organized a hands-on course where participants learned how to make graphics visually attractive, and how to better illustrate scientific findings.

Digital conferences and the widespread use of social media are increasingly requiring higher quality illustrations of scientific results. To build competence in presenting scientific results, the Nansen Legacy project organized a one-week hands-on graphical design course. While the course was originally intended for early career scientists, many senior scientists took advantage of this course to learn about the new techniques available in digital illustration.

The course was led by graphical communicator Pina Kingman, who introduced general theories and hands-on methods of how to visually present scientific results. The course covered different topics from color to design theory, understanding how to create visually powerful illustrations, as well as concept development. The latter addressed the complex task on how to distill information from comprehensive multifaceted scientific results into a brief and coherent story, and then turn it into an illustration. Furthermore, Nansen Legacy scientists were introduced to Adobe Illustrator and an alternative vector illustration software and gained hands-on experience.

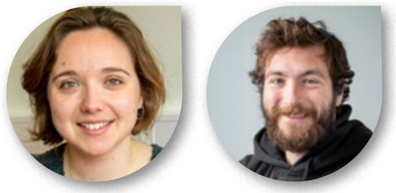
By the end of the course, all 16 participants had created a digital artwork of their research, aided through group peer-to-peer review and brainstorming sessions, and through personal reviews by the instructor. The graphical competence acquired during the course will strengthen the communication of Nansen Legacy results and science communication but also provided all the participants with useful tools for future scientific communications. ■

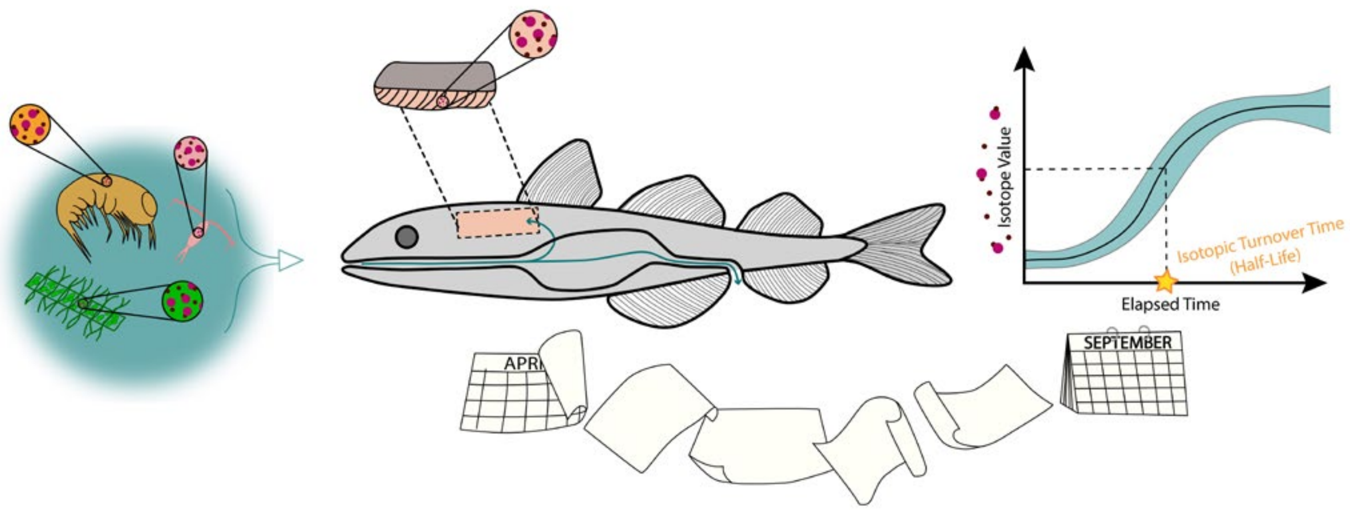


Four layers of sea ice surface resolution.
Scientific illustrations created by Adam Steer.

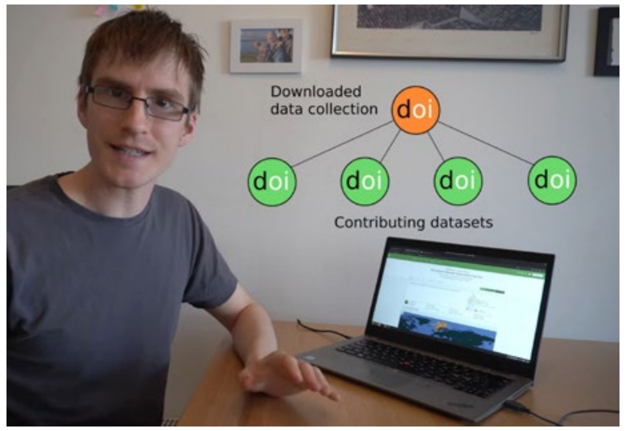
"We got great advice from Pina, and also it was extremely helpful to have the feedback from peers about our creative processes and final illustrations."

Griselda Anglada Ortiz, UiT and Eric Jorda Molina, Nord University





Isotopic work with fish.
Illustration by Amanda Ziegler



Luke Marsden providing additional help for the scientists with his Youtube video on "Darwin Core Archives and how to create them" (https://youtu.be/1Fuq8VZW_4c)

Marine data publishing workshop

Darwin Core is an international standard used for biodiversity datasets, intended to facilitate better information sharing across disciplines. Nansen Legacy scientists gathered for an in-person workshop to learn more.

Both scientists and technicians within the Nansen Legacy project met in September for a 3-day workshop in Tromsø. The aim of the workshop was two-fold. First, the participants learned about the publication of biodiversity data using the Darwin Core standard. Second, scientists and technicians worked with their own data collected within the Nansen Legacy project. With the hands-on help of Nansen Legacy data manager Luke Marsden (UNIS) as well as the specialists from the Ocean Biodiversity Information System (OBIS, https://obis.org) and the Global Biodiversity Information Facility (GBIF , https://gbif.org) participants learned how to format various data sets correctly. These datasets were made ready for publication within the GBIF and OBIS repositories.

Workshop participants found the practical approaches of the workshop very useful, and everyone agreed that having assistance from the specialists was helpful. Positive results of the workshop could already be seen later in 2022, with 17 new biodiversity datasets on ice algae, phytoplankton, and zooplankton published from the Nansen Legacy project. ■

Nansen Legacy early career scientists working during the retreat.
Photo: Khuong Van Dinh

Early Career Writing Retreat

Writing scientific publications can sometimes feel isolating. Nansen Legacy Ph.D.s and Postdocs joined forces against this struggle and came together during a 5-day writing retreat.

Early career scientists can often feel overbooked. Between sample analyses, teaching, taking courses, and sometimes supervising younger students, it can be hard to take the time to sit down in front of the computer and write a scientific publication. The Nansen Legacy Ph.D.s and Postdocs know about this challenge and faced it together. During a 5-day writing retreat at the Sommarøy Arctic Hotel, with the sole focus on writing, they helped one another in moving their scientific work forward. Spending the days working in pairs or alone, participants took the time to enjoy cooking and eating dinner together. ■

Ph.D. and Master theses 2022

In 2022, one Ph.D. and six master students defended their degrees. Congratulations to all of them for their successful work.

Elliot Sivel graduated from UiT and is the first Ph.D. student earning a degree from the Nansen Legacy project (supervisors: B. Planque, U. Lindstrøm, both IMR, N. Yoccoz, UiT). Elliot's work suggests that both climate change and fisheries affect the variability of the Nordic Seas, but that these stressors should not be considered separately for management. His work proposes that food-web modelling based on the principles of Chance and Necessity can be used as a tool to inform adaptive management, ecosystem-based management, and integrated ecosystem assessment.

Reference: Elliot Sivel (2022) Investigating the drivers of the Nordic Seas food-web dynamics using Chance and Necessity modelling. Ph.D. thesis, UiT The Arctic University of Norway

Matthew Adams successfully defended his thesis at NTNU (supervisor: M.V. Ardelan, M.G. Digernes, both NTNU). He characterized the seasonality of dissolved organic matter (DOC) in the northern Barents Sea in relation to the mercury cycle. DOC showed a significant increase from late winter to spring, and mercury analysis suggested potentially dynamic and rapid methylation/demethylation processes.

Reference: Matthew Adams (2022) Characterisation of seasonal Dissolved Organic Matter from the northern Barents Sea, in relation to the mercury cycle. Master thesis, Norwegian University of Science and Technology

Sine Sara Astad completed her master thesis at UNIS and UiT (supervisors: J. Søreide, A. Vader, both UNIS, M. Daase, UiT). Her work focused on the distribution, population structure and size range of the different zooplankton species of *Pseudocalanus* in the Barents Sea-Svalbard region. Sine-Sara found that *P. acuspes* dominated in Arctic fjords in Svalbard and in the northern Barents Sea. *P. minutes* seemed to have no environmental preferences, while *P. moultoni* had a more southernly distribution.

Reference: Sine Sara Astad (2022) A spatial and temporal study of *Pseudocalanus acuspes, P. minutus* and *P. moultoni* in the Svalbard – Barents Sea region and their potential as environmental indicator species in a changing Arctic. Master thesis, UiT The Arctic University of Norway

Lia F. Herrmannsdörfer successfully defended her master thesis at UiO (supervisors: M. Müller, MET, T.K. Berntsen, UiO). She compared the global atmospheric model ERA5 with observation in the Arctic (MOSAiC campaign, winter 2019/20) and satellite data. Lia shows that the mean surface temperature error is 15°C in some parts of the Arctic, mainly due to insufficient representation of ice thickness and snow depth.

Reference: Lia F. Herrmannsdörfer (2022) Model Deficiencies of ERA5 Atmospheric Reanalysis Over Arctic Sea-Ice - Analysis of the Winter Surface Radiative Energy Budget by Using MOSAiC and Satellite Observations. Master thesis, University of Oslo

Laura Maria Kull graduated from NTNU (supervisors: M.V. Ardelan, S.G. Kohler, both NTNU). She studied the distribution of total mercury (THg) by analyzing surface sediments and core samples from the Barents Sea (BS) and the central Arctic Ocean. A significant correlation was found between THg and sediment depth, organic carbon, and manganese. Significantly less THg was found in the eastern BS than the western BS and it seems there is little to no anthropogenic input of total THg to the area.

Reference: Laura Maria Kull (2022) Total Mercury Distribution in the Barents Sea and the Arctic Ocean Surface Sediments. Master thesis, Norwegian University of Science and Technology

Andreas Jortveit finished his master thesis at UiO (supervisors: K. Borgå, K.V. Dinh, J. Titelman, all UiO, J. Søreide, UNIS). He studied the effect of warming, ocean acidification, and hydrocarbons on the early life stages of the Arctic zooplankton *Calanus glacialis.* Andreas shows, among others, that mortality was high in pyrene-exposed nauplii at elevated water temperature (5 °C). Results therefore suggest that pyrene is more lethal to *C. glacialis* in a future, warmer Arctic.

Reference: Andreas Jortveit (2022) Interactive effects of temperature, ocean acidification, and pyrene on *Calanus glacialis* nauplii Master thesis, University of Oslo

Marius F. Maurstad defended his master thesis at UiO (supervisors: S. Jentoft, S.N.K. Hoff, both UiO). He used newly generated chromosome-anchored genome assemblies of Arctic cod and polar cod and population sequencing data from both species to investigate the genetic relationship between the Arctic cod, polar cod, and other closely related species. Marius also studied past demographic history of fish and potential signals of contemporary hybridization events.

Reference: Marius Filomeno Maurstad (2022) Identification of multiple chromosomal inversions in Arctic cod (*Arctogadus glacialis*) – and its putative implications for defining interspecies relationships. Master thesis, University of Oslo

Photo: Christian Morel/christianmorel.net

Yasemin Bodur (background), Ingrid Wiedmann (bottom left), and Marti Amargant Arumi (bottom right) at Forskningsdagene.
Photos: Jan Fredrik Frantzen, UiT.

Outreach

Nansen Legacy scientists continued their efforts to share scientific knowledge on the Arctic Ocean with children, fellow scientists, and the general public. Here are some glimpses of our various activities.

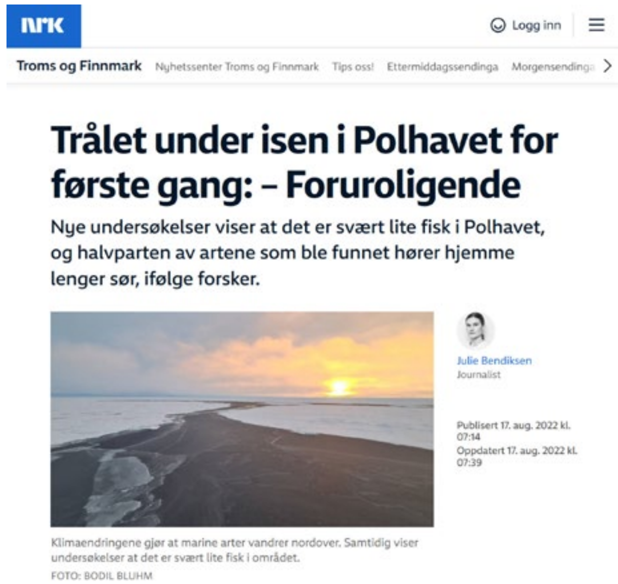
For and with kids

Yasemin Bodur, Martí Amargant Arumí, and Ingrid Wiedmann (all UiT) had an educational booth for children at the Vitensenteret during the Norwegian Research Days. Their saltwater experiments, microscope tutorials, and an introduction to marine snow, were well-received by all who visited. Lena Seuthe, former project administrator in the Nansen Legacy, carried her passion for the Arctic Ocean to her new position at the UiT school lab. There, Lena educated 10th graders on the effects of ocean acidification and marine heat waves in the Arctic Ocean, and informed upper secondary school students about Arctic ecosystem changes. Øyvind Lundesgaard (NPI) and Angelika Renner (IMR) travelled to several smaller towns in Northern Norway as part of the Research Days activity «Forskerne kommer» and shared their excitement for the Arctic Ocean and sea ice with students in the countryside.

Angelika Renner (IMR) presenting during the research days.
Photo: Helge Markusson

For and with public

Early Career Nansen Legacy scientists shared scientific snapshots in 24 Instagram posts (@nansenlegacyresearch) and PI Marit Reigstad was part of the Instagram story "Kaffe med en forsker". Artist Lena Gudd created the online multimedia story "In Nansen's footsteps" (https://arcg.is/11anem0) illustrating how art and science come together in Arctic research. Nansen Legacy scientists shared their knowledge with journalists, and local and national media, resulting in three articles by the Norwegian Broadcasting cooperation (trawling in the Arctic Basin, marine heat waves, and extreme precipitation in the Arctic). Other articles were published in the newspapers Nordlys, Klassekampen, Wormser Zeitung, the journal Tekninsk Ukeblad and other print media.



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Trålet under isen i Polhavet for første gang: – Foruroligende

Nye undersøkelser viser at det er svært lite fisk i Polhavet, og halvparten av artene som ble funnet hører hjemme lenger sør, ifølge forsker.

Julie Bendiksen
Journalist

Publisert 17. aug. 2022 kl. 07:14
Oppdatert 17. aug. 2022 kl. 07:39

Klimaendringene gjør at marine arter vandrer nordover. Samtidig viser undersøkelser at det er svært lite fisk i området.
FOTO: BODIL BLUHM

Research from Nansen Legacy was broadcasted by NRK in 2022
(screenshot from https://nrk.no, 17 Aug 2022)

For and with scientists

Nansen Legacy researchers presented their work at 37 different international conferences with 17 posters and 53 oral presentations. Among others, they contributed to the Arctic Science Summit Week in Tromsø. The early career scientists Julia Giebichenstein (UiO), Chrissie Gawinski (UiT), and Robynne Nowicki (UNIS) shared their experiences in a science communication workshop. Arild Sundfjord (NPI) and Marit Reigstad (UiT) led a discussion on future scientific observations within the Atlantic sector of the Arctic Ocean. Sebastian Gerland (NPI), chair of the science day committee, organized a program in Arctic remote sensing with Katalin Blix (UiT) as keynote speaker. Miriam Marquardt and Marcela Conceicao do Nascimento (both UiT) informed conference participants about the Nansen Legacy project.

Camille Li (UiB) was an invited speaker at the annual meeting of the American Geophysical Union in Chicago, Illinois (USA). Camille presented results on the synthesis work that examines the linkages between Arctic sea ice and Eurasian cooling. ■

Ingrid Wiedmann, Marit Reigstad, and Miriam Marquardt at the Nansen Legacy booth during the Arctic Science Summit Week.
Photo: Estelle Coguiec

International collaboration and mobility

The Nansen Legacy project is tightly connected to the international Arctic research arena through mobility and collaborations with various researchers, projects, and institutions around the globe. Two stories of our 2022 collaborations are highlighted here.

An engaging research visit

In the spring of 2022, Jakob Dörr, a Ph.D. candidate in climate dynamics, visited the California Institute of Technology (Caltech) in Pasadena, California (USA). Jakob worked with a Caltech Ph.D. candidate Dave Bonan and collaborated on their shared research interests in understanding present and future changes in Earth's sea ice cover and the processes that affect its variability. Jakob spent one month at Caltech to work on a statistical technique that separates modes of sea ice variability over long time periods (decades and longer) in the observational records of Arctic and Antarctic sea ice.

During the visit, Jakob and Dave exchanged their research experiences and discussed new ideas for analyses. Jakob also interacted with other scientists studying oceanography and climate dynamics at Caltech, involving himself in a sea ice reading course taught by Professor Andrew Thompson that covered sea ice models and observed sea ice trends. In the end, Jakob had a lot of fruitful interactions and learned how science is conducted at Caltech and other U.S. institutions.

Early career researchers continue their collaborative work

The collaboration between Jakob and Dave continued into the autumn of 2022. With the support of Nansen Legacy, Dave visited Jakob and Marius Årthun at the University of Bergen (UiB). Together, they used Dave's research visit to further discuss mechanisms of sea ice variability and worked on two separate publications on Arctic and Antarctic sea ice. This work includes a collaborator from the University of Washington (USA). Dave and Jakob also plan on applying the same method to climate model simulations of future sea ice change.

During Dave's visit at the Geophysical Institute at UiB, he interacted with many Norwegian scientists and gave two seminars about changes to the Atlantic overturning circulation and large-scale hydrological cycle under warming. Camille Li (UiB) suggested that he return in the winter, because of Dave's love for skiing.

"I hope that I can continue the collaboration between Caltech and the Bjerknes Center beyond our work on sea ice observations."

Jakob Dörr

Jakob and Dave discuss science at UiB.
Photo: A. Jaison

"My only complaint was that my visit was far too short! I look forward to returning and to continue my interactions with people at UiB."

Dave Bonan

Marine Warriors in Vietnam

Nansen Legacy post doctorate fellow Khuong V. Dinh from the University of Oslo had the exciting opportunity to share some of his research at a Young Southeast Asian Leaders Initiative (YSEALI) workshop in Nha Trang, Vietnam. The YSEALI community consists of bright young leaders from 11 Southeast Asian countries who are making a difference in their communities and countries. The workshop, supported by the U.S. Department of State, invited 100 participants to study and observe the latest consequences of environmental changes occurring in Vietnam, caused by plastic pollution, ocean acidification, and fisheries management, to name a few.

Khuong presented his work to the workshop participants and discussed some of his findings from the Nansen Legacy in his presentation entitled, "Impact of environmental pollution and climate change on marine life." The workshop participants learned both short- and long-term solutions through presentations such as Khuong's, in addition to site visits and interactive activities. The young leaders also learned about comprehensive solutions to address the issues that face coastal and marine environments in Vietnam and other Southeast Asian nations. ■

Khuong presenting his work to the 100 young leaders at YSEALI.
Photo: YSEALI Flicker https://www.flickr.com/photos/yseali/

"The workshop was amazing, and it was my great honor to share our research on how humans impact marine life with 100 young leaders from 11 Southeast Asian countries!"

Khuong V. Dinh

Project collaborations and further use of data

The ***Year of Polar Prediction*** (YOPP, https://www.polarprediction.net/) was an international initiative to improve the environmental prediction capabilities in polar regions. An important element was to improve weather forecasts and environmental prediction services. The Nansen Legacy contributed with field observations to the YOPP Special Observing Periods (and beyond) with regular radiosonde releases from *RV Kronprins Haakon*. Results from this collaboration are improved forecasts of strong winds and large waves for the European Arctic, as well as improvements on snow and sea ice models, which will be included in operational weather forecasting systems.

The Nansen Legacy contributed to the ***Synoptic Arctic Survey*** (SAS) Initiative (https://synopticarcticsurvey.w.uib.no/) with the Arctic Basin cruise in 2021 (see our 2021 annual report). Through a series of ongoing science sessions and workshops, results are now being discussed to facilitate synthesis and an integrated understanding of the Arctic Basin based on the many synoptic cruises that have covered different areas of the Arctic Ocean.

A ***Distributed Biological Observatory*** (DBO) has proved to be a successful concept that increased and connected the observational capacity in the Pacific Arctic by the selection of a set of established or new stations where an international community focused their observations. A similar initiative by Arctic Passion (EU) and the Nansen Legacy is presently in progress in the Atlantic Arctic, *A-DBO* (https://arcticpassion.eu/adbo/), to connect observations on selected stations from time series operated by different nations and institutions. The ambition is a sustainable future observational network where some of the Nansen Legacy stations will also be included. ■

Photo: Andreas Wolden

Interactions 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 new knowledge help society overcome the challenges posed by a rapidly changing climate? The Nansen Legacy interacts with society in several ways and works towards synthesizing and communicating knowledge and results in a way that enhances dialog with users outside the scientific community.

Picture: Marit Reigstad speaks with Queen Sonja of Norway about the Nansen Legacy Project.
Photo: Mette Mila, RCN

Arctic Frontiers side event "From Science to Policy to Impact in the Arctic"

How can an emerging scientist be better equipped to influence and inform policy making? That was one of the questions moderator and co-PI in the Nansen Legacy project Tor Eldevik challenged to the panel. Post doctorate Alun Jones (NTNU and Nansen Legacy), Professor Lise Øvreås (Nansen Legacy member and president of the Norwegian Academy of Science and Letters), Espen Barth Eide (Norway's Minister of climate and environment), and Marie-Anne Coninsx (EU's first ambassador (2017–2019) for the Arctic) all joined in the panel discussion. Barth Eide and Coninsx found their policy domain, including the Arctic, to be guided by science. Central measures in transferring science to policy seems to be an immense task and there are established community efforts such as the Intergovernmental Panel on Climate Change (IPCC) and a collective display of ongoing research at the Arctic Science Minsterials. A Danish journalist/lecturer in the audience however made a good point, in that informed media may have a (potentially under-explored) key role as a mediator in the knowledge transfer from science to policy.

The ocean – a hot topic on the societal agenda

Project PI Marit Reigstad and Lars Smedsrud from the Nansen Legacy participated in the Lavvu and campfire discussion on why the seasonal ice zone and sea ice edge is such a hot topic for both the petroleum industry and Arctic ecosystems during the Arendalsuka. They were accompanied by the Minister of climate and research, Espen Barth Eide, politicians, and members from the petroleum industry and various management entities. Arguments on energy needs, new plans for petroleum exploitation, and how and why the ice edge is a hot spot for life resulted in a lively debate.

Knowledge status and future perspectives on the Barents Sea were also topic under a session on the Ocean Decade during the Nor-Fishing 2022 meeting. During this event, the Queen of Norway was also informed about the Nansen Legacy project. The Norwegian Ministry of Education and Research, one of the main funders of the Nansen Legacy, invited PI Marit Reigstad to their international Compass conference. Organizers were eager to hear about the research and knowledge status for the Barents Sea when they identified Norway as a leading ocean and polar nation.

Trainees for the foreign ministry and the seafood industry

The future ambassadors to Norway, participating in a trainee program offered by the Ministry of Foreign Affairs, were updated on the status and challenges in the Arctic Ocean when visiting northern Norway and UiT. Using sustainability as a guideline, communication with the future ambassadors was inspiring and important to strengthen Norway as an ocean and polar nation.

Nansen Legacy PI Marit Reigstad gave lectures for trainees participating in a national program, the Norwegian Centres of Expertise (NCE) Seafood Innovation Cluster. Trainees built networks and increased their competence on subjects covering the importance of the growing seafood industry. Trainee seminars in both spring and autumn 2022 were co-organized by the Nansen Legacy reference group members Biotec-North and Line Kjeldsrup.

ONE Ocean Summit 2022

This summit, held in Brest, France, was hosted by the French president Emmanuel Macron. The summit gathered 37 international leaders representing all ocean basins. A series of seminars and workshops were included. Nansen Legacy PI Marit Reigstad was invited to report on one of the discussions during the Polar Oceans workshop. The message from the workshops given to the head of states during the summit was delivered by Antje Boetius, the director of the Alfred Wegener Institute for Polar and Marine Research. Boetius, who also serves on the Nansen Legacy Scientific Advisory Board, stated, "International collaboration and action are needed to reduce climate impact, biodiversity loss and fragmented governance." ■

Photo: Christian Morel/christianmorel.net

Photo: I. Wiedmann

Extreme precipitation events occur more frequently in Svalbard during winter

Svalbard experienced several extreme precipitation events during winter in the past decade. This led to an increased risk of slush avalanches and ground-ice cover and caused problems for both humans and animals. Since 2012 several unprecedented extreme events have been observed. Researchers have now reanalysed the weather between 1981 and 2018 to understand how these events are possibly connected to our changing climate. They found that the declining sea-ice cover on the east coast of Greenland can be connected to the increasing frequency of extreme precipitation in Svalbard.

Using models to fill observational gaps

In January 2012, Svalbard had two weeks of extreme weather. The air temperature in Longyearbyen increased to 4 °C and heavy rain brought approximately 70% of the mean annual total precipitation. Because of this weather, avalanches damaged infrastructure, and ground-icing stopped air travel. When temperatures returned to sub-zero norms, the ground ice caused challenges for people traveling by snowmobiles or dog sledges. It was unclear if these extreme precipitation events had become more frequent on Svalbard in recent years because studying precipitation in Svalbard is difficult with only a few long-term precipitation measurements available. Researchers have now used models to reproduce the weather on Svalbard between 1981-2018. Analyses of the data showed that the chance for extreme winter precipitation, as was observed in 2012, had indeed strongly increased over the last 40 years.

Sea ice at the east Greenland coast shields west Svalbard from intense precipitation

Combining atmospheric data between central Greenland and the Barents Sea with the sea-ice coverage of the Greenland Sea revealed some mechanisms affecting the precipitation in Svalbard. Moisture and relatively warm air from the Northern Atlantic are generally transported northwards when a high-pressure field resides over Scandinavia and the Barents Sea, and a low-pressure field is located over Greenland. If a large sea-ice cover is present on the east Greenland coast, Svalbard seems to be shielded from extreme precipitation events. First, the warm and moist air from the south is likely lifted when it reaches the sea ice in the Greenland Sea, because cold air is present over the sea ice. This lifting results in precipitation over the sea ice and the Greenland Sea. Second, air transported towards the north does not gain any additional moisture, because sea ice hinders evaporation. These processes, when combined, contribute to less water vapor reaching Svalbard. In a situation with small sea-ice cover along the east Greenland coast, however, the precipitation over the Greenland Sea is weaker and more water vapor can be brought to Svalbard, causing extreme precipitation events.

More extreme precipitation on Svalbard in the future

This study clearly shows that the extreme precipitation events on Svalbard have become more frequent in recent years and that this phenomenon is connected to the reduced sea-ice cover in east Greenland. As the sea-ice extent in the Greenland Sea will likely further decline, people and animals on Svalbard will experience more extreme precipitation events in the future. ■

> "With the further decline of sea ice coverage east of Greenland, the recently observed precipitation extremes will become even more frequent."

Malte Müller, MET

References:

Müller M, Kelder T, Palerme C (2022) Decline of sea-ice in the Greenland Sea intensifies extreme precipitation over Svalbard. Weather and Climate Extremes 36: 100437.

Work with the user groups

Paul Renaud, researcher at Akvaplan niva, has joined the administrative team in 2022 to ensure an even better dialog and involvement between the Nansen Legacy science project and the user groups. Read more about this experience below.

- Paul, you joined the Nansen Legacy project administration to ensure an even better dialog and involvement between the Nansen Legacy science project and the user groups. Can you first share with us who is the Nansen Legacy user group?

In theory anyone and everyone can be a user of Nansen Legacy results. Students at all educational levels are interested in what is happening in the Barents Sea. Many businesses are dependent, directly or indirectly, on a healthy and well-managed Barents Sea. And the public is also interested, whether they sit in Hammerfest or in Kristiansand. We try to reach out to all these groups in our dissemination activities through the Communications Team. In Nansen Legacy, we also have a Reference Group, which includes representatives of many of the primary users of project results. This group includes eight institutions: four from regional and national policy and management entities, two international advisory bodies, and two industry interest groups. We also have good contact with the group within the Norwegian Environmental Agency responsible for synthesizing knowledge forming the scientific basis for the regional management plans for Norway's marine areas.

- What results and knowledge from the project do you think will be considered most beneficial, and how is the science made useful?

The broad combined interests of the Reference Group mean that most of the project results are interesting to someone. In particular, results that improve ice and weather forecasting, fisheries resources, pollution impacts, environmental monitoring, and projections for climate-related changes in the physical, biogeochemical, and ecological components of the Barents Sea system are most immediately relevant. We also need to recognize that the technology and models developed within Nansen Legacy and the archived data sets produced by the project will most likely have the longest impact for users, in addition to being of immediate value for some user groups. We have been in close contact with user group representatives since the project began and most of them have provided us with a list of how Nansen Legacy can contribute to their knowledge needs. In the last year we have increased our dialogues by including a Reference Group representative on the Nansen Legacy Board, inviting Reference Group members to participate in webinars, Task Force meetings, and the Annual Meeting. Several members have been very active in these events and the input they provide helps guide our planning of project deliverables.

- From your experience, what are some of the lessons you have learned from bridging a science project and its user groups?

Rolf Rødven (AMAP) from the Reference Group giving a talk at the Nansen Legacy Annual Meeting 2022.
Photo: Trude Borch

Well, there is a reason that few projects have wide success in navigating this science-society interface, and in Nansen Legacy the breadth of interests among potential users further complicates this issue. There is a wide gap between how scientists communicate their results and how business, managers, politicians, and the public want to receive information. Our job is not only to understand what users want to know but also the format in which it needs to be communicated. Some are satisfied with scientific articles and data sets whereas most need results synthesized in very applied manners. This remains a challenge, and not many scientists have the necessary experience. But through our Communications Team, Secretariat, and some of our researchers who have skills in this area, we hope to achieve many of the user-related project goals. And this represents an arena where early-career scientists can get valuable training if they are interested.

- Do you plan any specific events in the future to communicate the newest scientific findings to the Nansen Legacy user group?

New research findings will be more clearly communicated through press releases that identify how results apply to the needs of different users. In response to wishes from several members of the Reference Group, we will hold an ice-data workshop where we make data sets and data products more accessible and applicable to the needs of users. Finally, the Nansen Legacy Symposium (https://nansenlegacy-symposium.com) in November 2023 will not only showcase scientific results of the project in a broader pan-Arctic context, but it will actively involve representatives from many users of the knowledge we are providing. Several presentations per session will be given by members of the user groups. ■

Data: Our key in understanding the future world

The Nansen Legacy project is now turning away from research cruises and long days in the field to results and information dissemination. While the project has gained more knowledge about the Arctic Ocean and Barents Sea, researchers have also collected an abundance of samples and data. Our data manager, Luke Marsden, advises project members on how to manage collected data following the best available practices.

Luke discussing data management with Oliver Müller at the annual meeting.
Photo: C. Stark

- What are the challenges to keep people interested in sharing their findings?

What makes this particularly tricky in Nansen Legacy is that we work with data from many different disciplines. But the biologists need to know what the geophysicists are up to, and the meteorologists need to know what the oceanographers are up to. So, we need a way to both keep track and present all of the data that we are collecting. We host a catalogue of metadata online – this doesn't include the data themselves, but instead includes who has been doing what, where and how.

- Is it challenging to communicate this to everyone across such a large project?

Good communication skills are an important part of being a good data manager – something I didn't realize when I took the job! I really enjoy this part of the job, whether it be writing e-mails, running workshops, giving presentations, or even creating YouTube videos - I try to spread any wisdom I have as broadly as possible!

- Can you discuss the importance of data standardization?

Imagine you made an Excel sheet to log all the different animals you saw throughout the day. Imagine your friend did the same. Would your Excel sheets look the same? Would you have used the same column headers? Would you have structured the files in the same way? Would you be able to understand everything that your friend did without asking them? Probably not. Now let's scale this up and imagine there are 1000 people with 1000 files. Would someone be able to write a single program to read and understand the data from all the files in the same way? Almost certainly not.

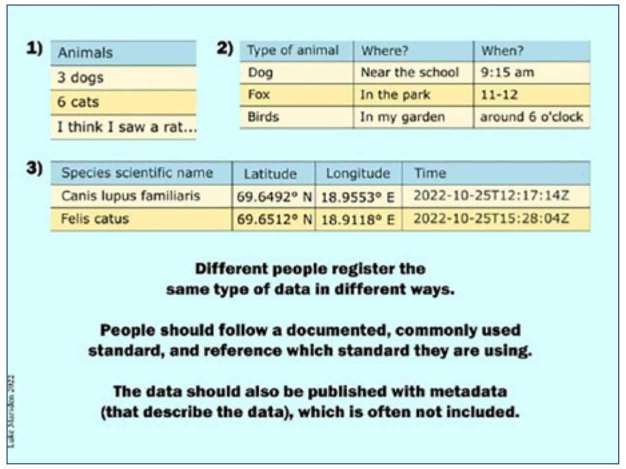
People should use file formats like NetCDF-CF or Darwin Core Archives where possible, which have a self-describing file structure, which means that the file includes information that tells a person or computer where everything is in the file. These files are self-containing, meaning that they contain a lot of metadata within the file that describes the data.

If computers can understand our data, they can more easily present many similar datasets together in the same way, which makes it easier for people to view, access, or understand the data.

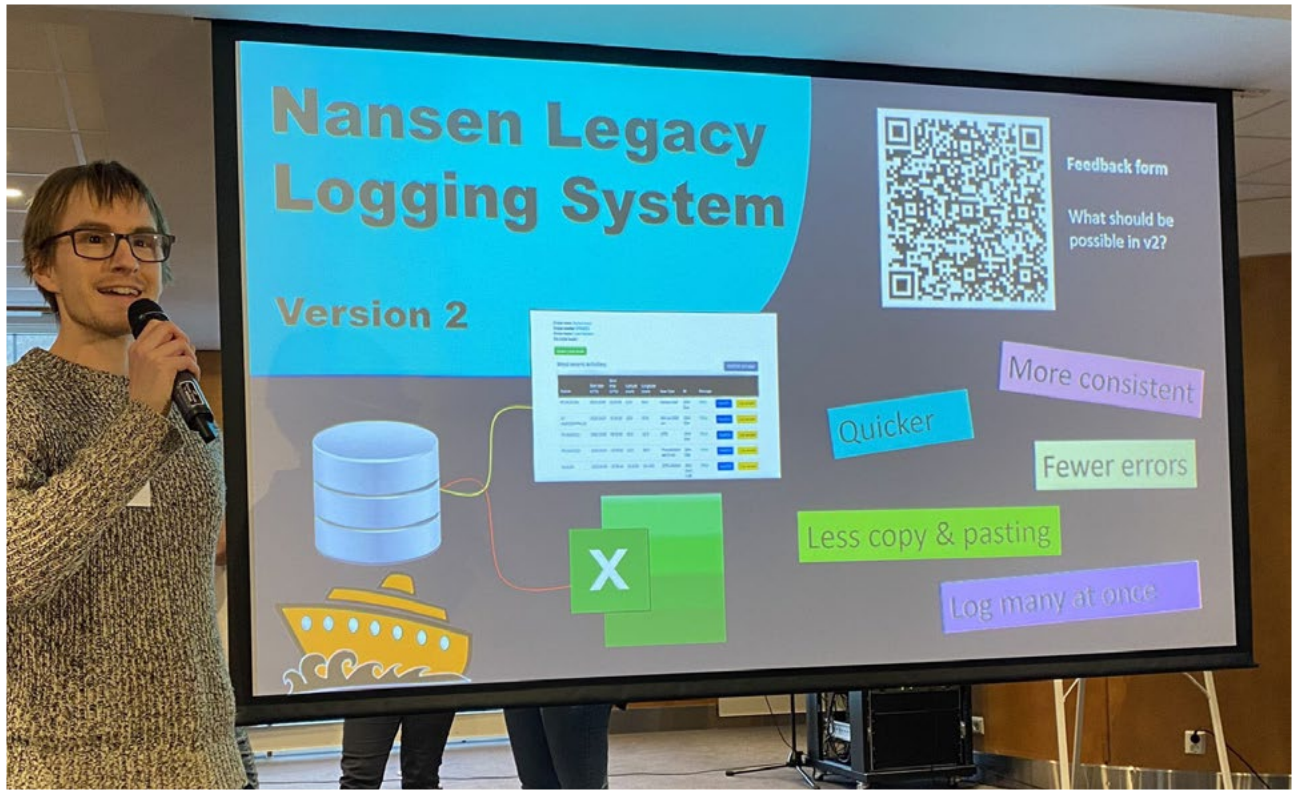
- How does one find the data they are looking for?

Some data centres are the default for a certain type of data. We have the Global Biodiversity Information Facility for example, where most people publish their biodiversity data. This includes over 2 billion observations of different organisms worldwide. Some institutions have data centres connected to them. For example, scientists at the Norwegian Polar Institute should publish most of their data with the Norwegian Polar Data Centre.

The Svalbard Integrated Arctic Earth Observing System (SIOS) hosts a data access portal that aims to provide access to all data published in and around Svalbard. This should be the starting point for anyone looking for data from the region. All Nansen Legacy data are tagged so it is easy to get an overview of all the data we have published. The number of datasets included is growing all the time!



Data design is not always easy because everyone has their own opinions on what needs to be recorded.

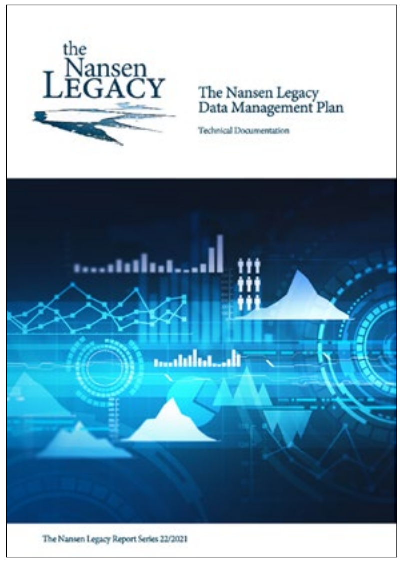


Introducing version 2 of the Nansen Legacy data logging system.
Photo: T. Eldevik

- Is good data management a legacy of the project?

Absolutely! The data we are collecting will be used in research for decades to come, maybe centuries in some cases. We are building a multidisciplinary picture of the Northern Barents Sea, one of the fastest warming places on the planet. If we want to understand the changes taking place here, we first must document the data. By publishing our data, we are making it easier for more people to research what we are observing. We can contribute to big datasets, far too large for any one person or project collect alone.

Perhaps even more importantly, we are setting a precedent for how data should be handled and published for the rest of Norway and the Arctic. Good data management is in its infancy in the Arctic but is much more mature in other fields. Take the World Meteorological Organization for example. We would not have such high-quality weather data or climate models without international exchange of standardized data. Who knows what will be possible with similar exchange of data becomes common practice in other disciplines? ■



Check out our links to the Nansen Legacy data policy and data management plans.

https://doi.org/10.7557/nlrs.5799
https://doi.org/10.7557/nlrs.5800

Luke's YouTube channel provides tutorials on data management and fair practices. These videos are available not only to project members, but also for the general public.

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. The examples below illustrate some of the advances the project has made with improved model and forecast tools, new methodologies, and improved predictive capabilities during 2022.

Mercury levels in marine mammals and at the sea floor

Mercury is one of the heavy metals that is mapped by the Arctic Monitoring and Assessment Program (AMAP). Nansen Legacy scientists contributed to a risk assessment review on the population of Arctic marine mammals that show low to no risk in the Barents Sea region. Mercury sinks to the sea floor with organic particles and accumulate in marine sediments, and Nansen Legacy scientists identified higher mercury concentrations in the deep Eurasian Basin than on the Barents Sea shelf. Sediment transport from the shelves to the deep Arctic Basin is the likely explanation.

New model tool to support ecosystem-based fisheries management

Model tools that can account for interactions between exploited populations and their prey is required for successful implementation of integrated ecosystem-based assessment in fisheries management. Limited and uncertain data on some of the species involved, however, is often a challenge. Chance and Necessity (CaN) is a new type of model that can handle limited and uncertain data. Using CaN, Nansen Legacy scientists evaluated the Norwegian Sea food webs over the past three decades. The results suggested that populations of the investigated small pelagic fish species seemed controlled by changes in food consumption rather than fisheries and predation. CaN models can help to prioritize future data collection by identification of what information is critical for robust ecosystem-based management.

Multiple stressors require long term observations of species and ecosystems

Species living in Arctic marine environments are not only exposed to a changing climate or pollutants transported from lower latitudes. These impacts are rather cumulative, often acting synergistically. New review papers from Nansen Legacy scientists underline the importance of both long-term monitoring of relevant biota and organisms and their habitats and ecosystems. Their findings also demonstrate that experiments on combined effects (both in the laboratory and in the field) are needed over sufficient time periods to identify effects from genetic- to ecosystem-levels.

Better tools to address oil in drifting sea ice

With reduced sea ice extent and thickness, the activity and traffic in areas close to the seasonal sea ice zone is increasing. Given that an oil leakage could eventually occur, scientists from the Nansen Legacy have evaluated the results of two different models on oil-in-ice drift versus field measurements from drift buoys and wave sensors deployed within the seasonal ice zone. Results show that oil spill particles travel further than the threshold of present-day marginal ice buffer zones, and the forcing by wind (for example) is crucial. An improved model reduced the error by a factor of two to three after 48 hours for ice drift furthest in the sea ice zone.

Predictability of sea ice change within the Barents Sea

Sea ice extent in the Barents Sea has become more dynamic, as a result of more open water and the northerly retreat of sea ice into the Arctic Ocean basin. Northerly winds have been found to influence sea ice import from the Arctic Basin into the Barents Sea, as well as redistribute sea ice within the Barents Sea region. The total area of sea ice in the Barents Sea are delayed responses to predictable drivers like Atlantic Water inflow and, to a certain degree, sea ice import. The redistribution of sea ice within the Barents Sea is however strongly influenced by wind and is less predictable. Our ability to predict the short time sea-ice dynamics resulting from redistribution of the sea ice is therefore limited, highlighting the importance of understanding wind patterns as it relates to sea ice dynamics.

Ecosystem responses to a warming climate

The influence of a warmer ocean on the Barents Sea ecosystem is important for a successful ecosystem-based management. Nansen Legacy research on how organisms in the ecosystem cope with marine heatwaves show that each heatwave caused a stepwise change in the responses of different fish species and communities in the Barents Sea. Organisms on the sea floor are less mobile when the environment changes, and mapping suggests that characteristic Arctic organisms and groups will lose space to more boreal species under warmer conditions. The smaller and more mobile organisms living under the sea ice seem more flexible to adapt to food from the water column as an alternative food source when that is available.

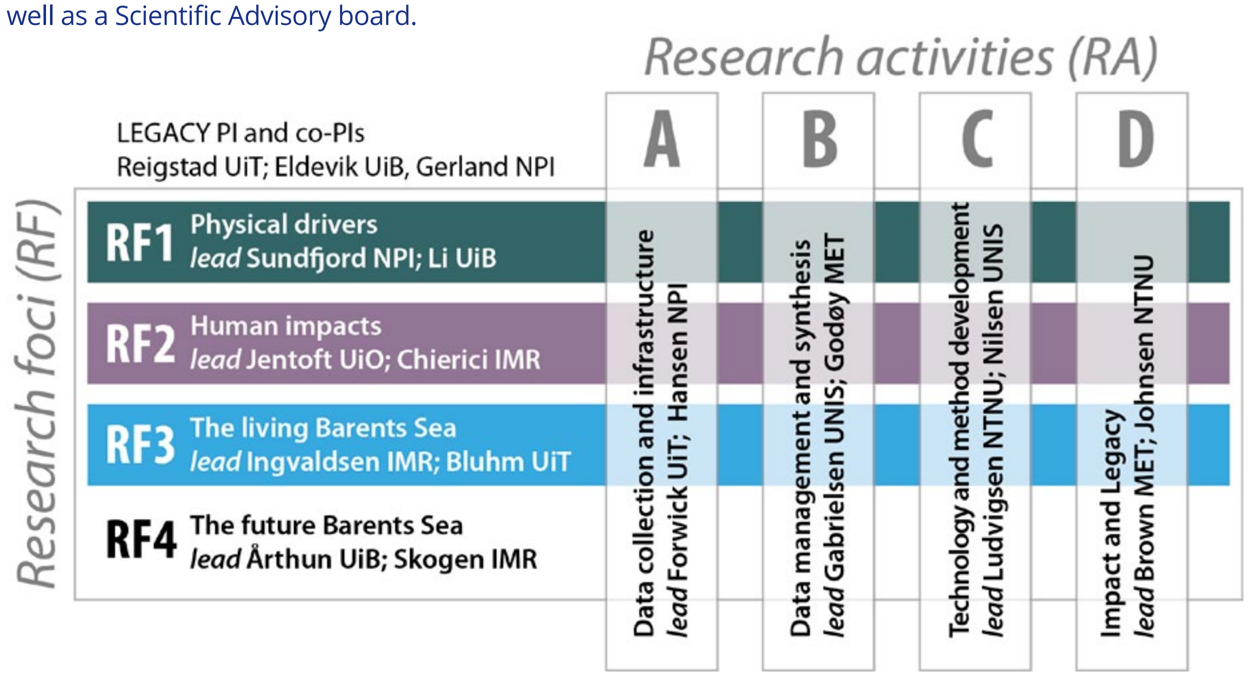
Contributing to major status and management reports

Nansen Legacy scientists have contributed to the international Integrated Ecosystem Assessment for the Central Arctic Ocean in 2022 (http://bitly.ws/CdFe). Such reports ensure a direct transfer of knowledge generated by the Nansen Legacy project into assessment reports used for management and policy making in Norway and worldwide. A working group (WGICA) with members from International Council for the Exploration of the Sea (ICES), the North Pacific Marine Science Organization (PICES) and Protection of the Arctic Marine Environment (PAME), studied and described various human activities in and around the central Arctic Ocean, and will continue to identify integrated assessment methods that will assist in the evaluation of ecosystem conditions and changes. ■

Photo: Christian Morel/christianmorel.net

Organisation

The Nansen Legacy is a collaboration between ten Norwegian research institutions, currently involving over 280 project members. Members include Ph.D. 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.



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, UiT

Tor Eldevik, UiB

Sebastian Gerland, NPI

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.

Prof. Tor Eldevik is co-PI of the Nansen Legacy and the Head of Department of the Geophysical Institute, UiB. 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 member of the Research Council of Norway's Portfolio Board for Climate and Polar Research.

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, NPI

Camille Li, UiB

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

Sissel Jentoft, UiO

Melissa Chierici, IMR

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, IMR

Bodil Bluhm, UiT

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

Marius Årthun, UiB

Morten Skogen, IMR

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

Matthias Forwick, UiT Håvard Hansen, NPI

The Nansen Legacy carries 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.

RA-B Data management and synthesis

Tove Gabrielsen, UNIS/UiA Øystein Godøy, MET

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.

RA-C Technology and method development

Martin Ludvigsen, NTNU Frank Nilsen, UNIS

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.

RA-D Impact and legacy

Nikki Brown, MET Geir Johnsen, NTNU

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.

Nansen Legacy annual meeting November 2022. Photo: Gudrun Sylte

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Julienne Stroeve	UK/Canada	University College London/ University of Manitoba
Timo Vihma	Finland	Finnish Meteorological Institute

Publications

By the end of 2022, the Nansen Legacy project reached a total of 154 peer-reviewed publications in high-ranking scientific journals. With a goal of adhering to open access publishing, many of our publications are available as open access (83%). The cross-institutional spirit of the Nansen Legacy is reflected in our publications, with 62% of our publications having two or more Nansen Legacy consortium partners. Our publications are also co-authored by scientists from 17 Norwegian institutions outside of the Nansen Legacy, demonstrating the integrative nature of the Nansen Legacy project within Norway. Our collaborations are also on an international scale, with 60% of our total publications to date including a myriad of research institutions outside Norway. These summaries reflect the impressive collaborative enthusiasm of the Nansen Legacy project.

Peer-reviewed publications

2022

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The Nansen Legacy in numbers

7 years

The Nansen Legacy is a seven-year project, running from 2018 to 2024.

280 people

Currently, there are about 230 researchers working with the Nansen Legacy, of which 73 are early career scientists. In addition, 50 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.

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.

Kunnskapsdepartementet

Funded by The Research Council of Norway

>350 days at sea

The Nansen Legacy has conducted 21 scientific cruises, equivalent to over one year at sea, in the northern Barents Sea and adjacent Arctic Ocean between 2018 and 2022. Most of these cruises were conducted on the new Norwegian research icebreaker *RV Kronprins Haakon*.

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