the Nansen LEGACY

Annual Report
2023

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The Nansen Legacy

Annual Report 2023

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Statement from the Board

The Nansen Legacy project is carried out by a national team covering a broad spectrum of expertise, involving indepth collaboration between several of the key research environments in the country. It was from its conception planned as one national project composed of several well integrated components, rather than as a program where individual (competing) research-groups could apply for funding. The Nansen Legacy has proved to be a very successful investment in long-term collaboration. Such a design has never been tried in Norway. The experience from the Nansen Legacy is very positive and worth adopting in similar future large national projects. The benefits of organizing the Nansen Legacy as one project was demonstrated through the final international conference "Towards the new Arctic Ocean – past present and future" hosted in Tromsø in November 2023, during which the results from all disciplines, partners and associated researchers were presented in coherence. Through the one-project approach, scientific results from various disciplines such as physics, biogeochemistry, ecology and technology - each operating on different temporal and spatial scales - were presented within the same framework and perspective.

As the project approaches its conclusion in 2024, the Nansen Legacy can look back on six years of joint research effort from 300 scientists and early career researchers, to establish a knowledge base for the seasonally ice-covered northern Barents Sea and the adjacent Arctic Basin. Eight Ph.D. and 27 MSc candidates have now finished their theses, and 56 postdoc candidates have worked in the project. Together, they form a unique recruitment pool for the future Arctic marine research community.

During the concluding months of the project, syntheses work, and careful off-boarding of personnel will take place. Focus will be on securing lasting products from the project (such as synthesized and pedagogic material for teaching) and integrating them into management and research channels, where the impact of the project will continue – the legacy of the Nansen Legacy. ■

Photo: Peter Leopold

Foreword from the leaders 2023: Towards the end of a journey



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

The sixth and last full year of the Nansen Legacy project has come to an end. While there is still work to complete in the final six months, we see that this long-term collaborative effort is nicely coming to its conclusion.

Our scientific ambitions setting out research in the Barents Sea included exploring the full seasonal cycle of both the environmental conditions and the ecosystem. We are therefore very happy to see the special issue on seasonality, edited by a team lead by Prof. Bodil Bluhm, is nearly completed with >20 publications in the scientific journal Progress in Oceanography.

Another grand ambition was the holistic understanding of the Barents Sea climatic and environmental system, from the large-scale drivers to the local responses. Dedicated interdisciplinary task forces were accordingly set up over the last two years, exploring and integrating the key themes investigated in the Nansen Legacy. As already manifested at our international Nansen Legacy Symposium in November 2023, and with the comprehensive fact sheets communicating the essence (including the brilliant illustrations of Frida Cnossen!), this main end-result – legacy – is about to be delivered. Well done all!

Examples include the influence of the Gulf Stream's northernmost branch, sea ice characteristics linked with ecosystems, human impacts like ocean acidification and contaminants, improved weather forecasts, and a future outlook, "the Barents Sea 2050".

The key messages from this work are presented in the abovementioned series of illustrated fact sheets to reach out to stakeholders and management, as well as scientist colleagues and the general public. The illustrations made by our eminent science illustrator Frida Cnossen, complements the emerging synthesized knowledge and conveys the new knowledge in a way that has already received much praise and inspired a broad audience.

Many of our early career scientists have been involved in this work, and as we approach the end of our journey, many have also finalized their important contributions to the Nansen Legacy. This new generation of Arctic researchers are already filling new positions nationally and internationally – in science, industry, and management.

The value of being part of such a large and interdisciplinary project is manifold. The interdisciplinary nature – across temporal and spatial scales – has educated everyone involved on the larger context of our Arctic marine research and fields of expertise, and how the different parts of the puzzle come together and the larger perspectives emerge.

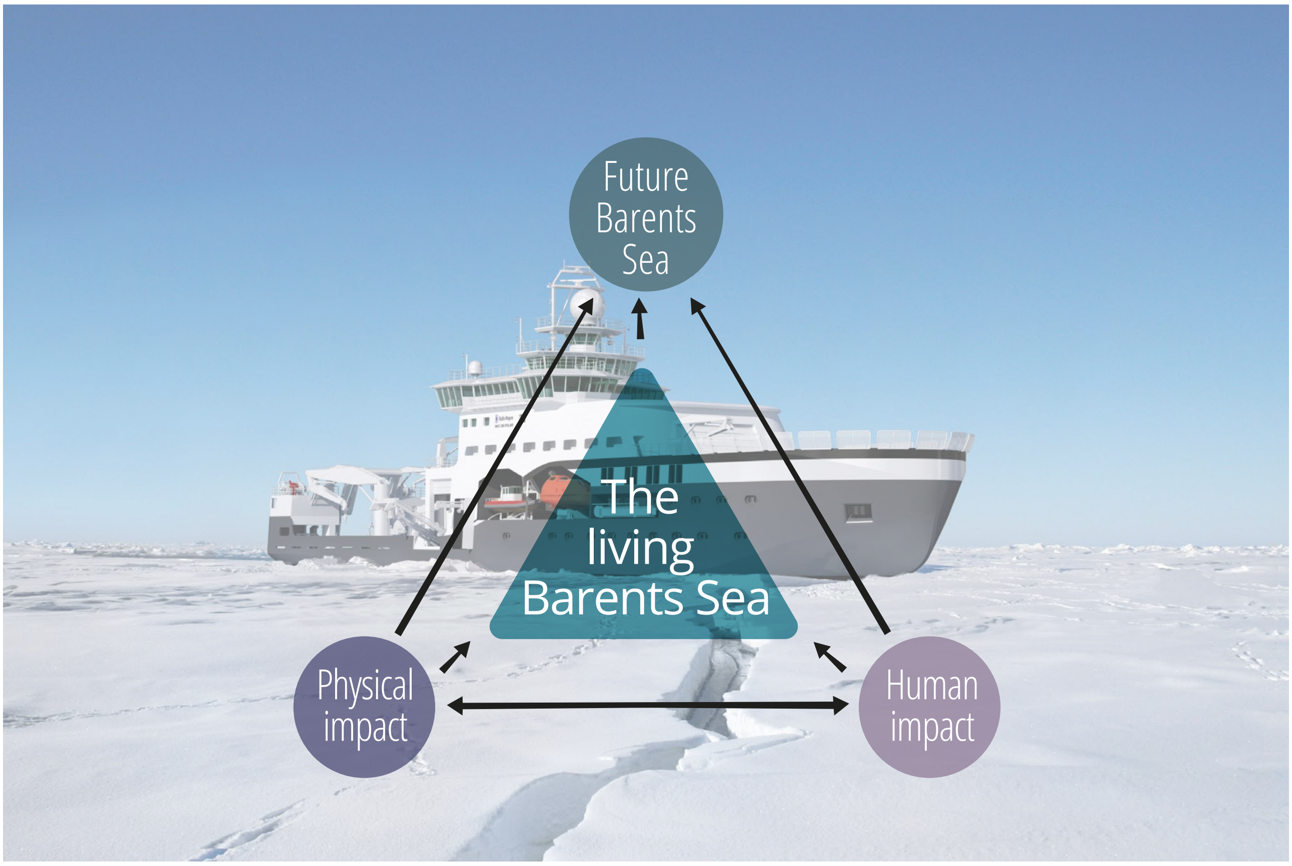
Through workshops, synthesis papers, production of fact sheets and thematic conference science sessions and side events there has been capacity to explore and connect the different pieces. The coordinated moorings and joint fieldwork around agreed stations and transect, standardization of methods and complementary approaches facilitated components that could be connected.

The project participants have also been educated on data publications. A series of workshops, YouTube videos and guidance by our data manager Luke Marsden on FAIR and proper data publication has resulted in a large and increasing number of published datasets that by far exceeded the record high number of scientific publications from the Nansen Legacy in 2023.

An exceptional effort like the Nansen Legacy involves both compromises and coordination of work to facilitate integration of data. This takes time and effort. It gives opportunities, new perspectives, access to infrastructure across institutions, new colleagues with complementary skills, supporting data and shared responsibilities. When the value of the opportunities exceeds the extra work coordination requires, the value of the overall results can be larger than just the sum of its pieces. We are confident that the Nansen Legacy team has achieved this added value.

The Nansen Legacy is getting close to the end of this journey - but it is the journey that matters in the end. ■

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: Andreas Wolden

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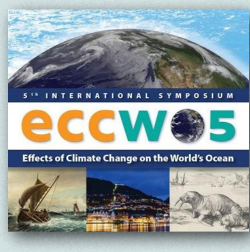
2023 in brief

Arctic Frontiers side event: During the Arctic Frontiers conference, the side event "Changing conditions in the Northern Barents Sea" engaged a discussion on the implications for marine services between Nansen Legacy members and users from the maritime sector.

Gordon Research Conference: Both senior and early career scientists from the Nansen Legacy participated in the Gordon Research Conference for Polar Marine Science, with several presentations. Our Ph.D. candidate Martì Amargant Arumì won a poster prize.



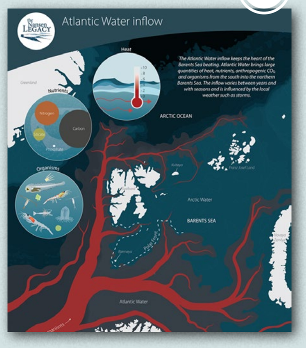
ECCWO5 symposium: Several Nansen Legacy members held presentations at the 5th International Symposium on the Effects of Climate Change on the World's Oceans in Bergen. The topics included Atlantification, human impacts, and implications for fish stocks in the Barents Sea.

ASLO conference: Nansen Legacy was well represented at the 2023 ASLO Aquatic Sciences Meeting in Palma de Mallorca, Spain. Early career and senior project members gave 9 oral and poster presentations, and an extended special session was organized by our Human Impacts task force group.

Winter

Spring

ASSW 2023: Nansen Legacy members joined the Arctic Science Summit Week (ASSW) in Vienna, Austria, organising and participating in several workshops and sessions with the international Distributed Biological Observatories (DBO) community, Arctic Passion, JAMSTEC and the Synoptic Arctic Survey.



Synthesis workshop – Atlantic Water inflow: An interdisciplinary group of Nansen Legacy researchers with a shared passion for Barents Sea oceanography, met to synthesize their findings on the Atlantic water inflow into the Arctic.

Nansen Legacy annual meeting: In 2023 the Nansen Legacy annual meeting took place in Oslo. On the final annual meeting, syntheses of results and new knowledge was in focus. A final dinner at the Fram museum gave a historic context to the Nansen Legacy project.

SAS workshop: Nansen Legacy scientist Agneta Fransson joined the international initiative Synoptic Arctic Survey (SAS) workshop in Woods Hole, USA, promoting pan-Arctic collaboration with data from the projects Arctic Basin and Fram Strait cruises in 2021.

Workshops: Two internal workshops were held, one to work on the Barents Sea 2050 synthesis article and a second Darwin Core workshop where participants brought and published project data in a standardized and FAIR way.

Nansen Memorial Lecture: Project leader Marit Reigstad was invited to give the Nansen Memorial Lecture of 2023. She presented results from the Nansen Legacy project for his Majesty the King and a distinguished audience and received the Nansen medal.

Annual production workshop: A workshop to evaluate and find the best ways to estimate total annual primary and secondary production in the northern Barents Sea.

More Workshops: Three workshops were held in November: one on publishing scientific data, one on using underwater hyperspectral imaging to study biological activity in ice covered waters, and one on comparisons of benthic diversity and carbon cycling in the Barents Sea and the deep Arctic Ocean.

Autumn

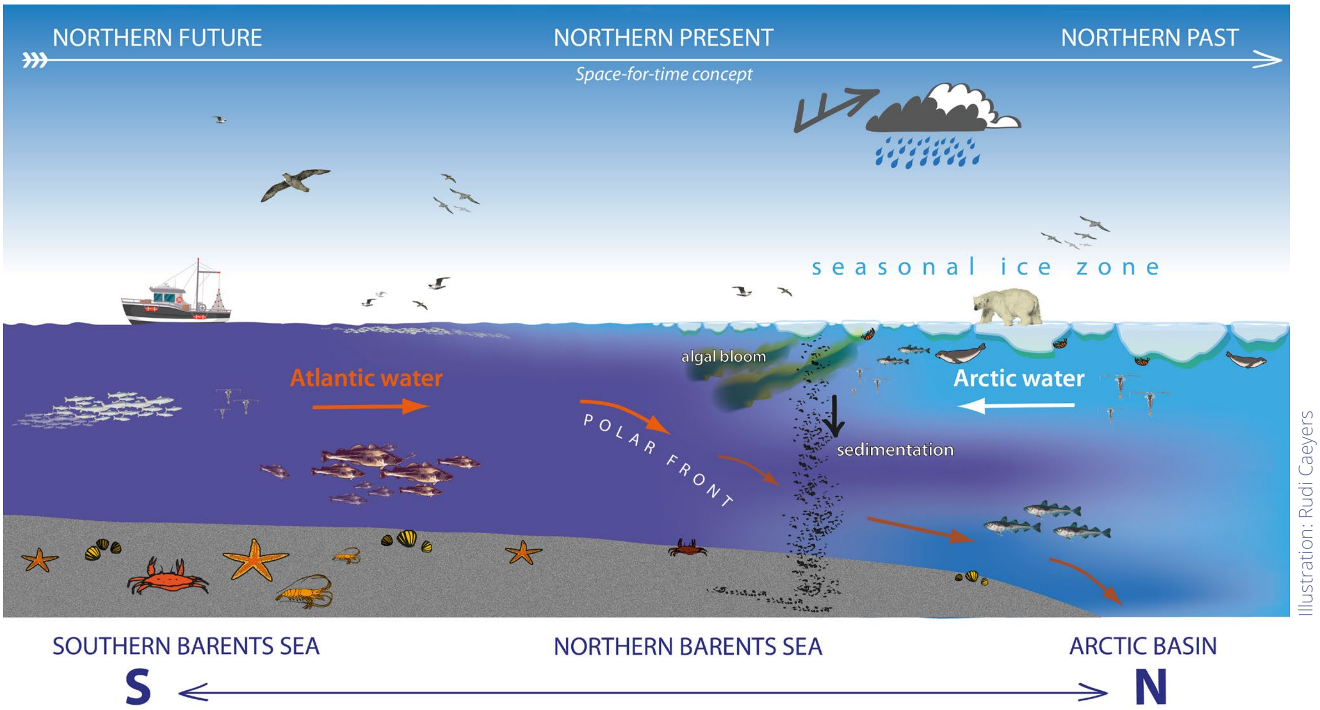
Summer

Arendal week: A panel discussing the upcoming Future Arctic Ocean project invited the Nansen Legacy to share its experiences from the unique scientific national team effort.

200 publications: In October the Nansen Legacy reached a new milestone – 200 peer-reviewed publications!

Early Career event: Early career scientists from and outside the Nansen Legacy joined forces to polish their skills in communicating science to policy makers and the general public, learning from two experts how to make an impact with the different audiences.

Symposium Towards the New Arctic Ocean – Past, Present, Future: In November, the Nansen Legacy hosted an international Arctic symposium in Tromsø, with more than 260 participants from all over the world. Excellent presentations facilitated discussions among the Pan-Arctic science community and management.



A changing Barents Sea – new overview of drivers and responses

The Barents Sea, as we knew it, is no more according to a new scientific publication from the Nansen Legacy. A review of the present knowledge on the large scale climate drivers and the responses seen in the physical, biogeochemical and biological systems brings together the parts of the complex larger Barents Sea system to understand why this sea stands out as one of the Arctic regions where climate and ecosystem changes are most pronounced.

Moving towards a new Barents Sea

The seasonally ice-covered northern Barents Sea has experienced extensive changes over the past two decades. This includes warming air and ocean temperatures, diminishing and more variable sea-ice cover, weakened ocean stratification, and alterations in water chemistry. These changes also affect the ecosystem. Some more southern species extend their distribution and can survive further north than before, and the productive season is prolonged. Long-term trends are documented across the ecosystem from the small primary producers via zooplankton and benthic organisms to fish, but with variability related to colder and warmer years. At the same time, there are some Arctic features like the extreme seasonality with polar night and midnight sun that stay the same, even if the climate changes. In the northern Barents Sea the winter is also still characterized by seasonally low air and water temperatures and sea ice cover. Despite trends in northward expansion, the main ecological communities in the central northern Barents Sea do therefore still reflect an Arctic ecosystem.

Complex changes taking place

The Barents Sea is closely connected to other regions, so 'what happens in the Barents Sea, does not stay in the Barents Sea´. The Barents Sea represents in many ways an early warning to changes that may propagate to other Arctic regions, including other shelf regions as well as the deep Arctic Basin. The Barents Sea is strongly impacted by the Atlantic Water inflow. The heat advected with the Atlantic Water is an important regulator of the sea ice extent, and is likely linked to the higher loss of winter sea ice in the Barents Sea compared to other Arctic shelf seas. At the same time, the winter sea ice in Barents Sea is increasingly dynamic and mobile. Locally produced sea ice is complemented with sea ice entering both from the north and the east, driven by wind. The sea ice conditions are thus in many ways less predictable and increasingly challenging for activities. This can affect the accessibility and the level of desired human activities in the area, such as cargo shipping, exploration of resources, fishing, and tourist cruises. In this way, changes in the sea ice distribution can also have a major impact on the economy of certain industries.

Future perspectives and observational needs

Model prediction on the future development of the northern Barents Sea identifies a dynamic system with high variability. Major trends are increasing temperatures, more fragmented sea ice and earlier retreat, increased ocean acidification and further northward migration of more boreal species. As this is a rapidly changing region with respect to the physical environment, the biogeochemical conditions, and ecosystem composition, it is important to follow the system closely in the coming

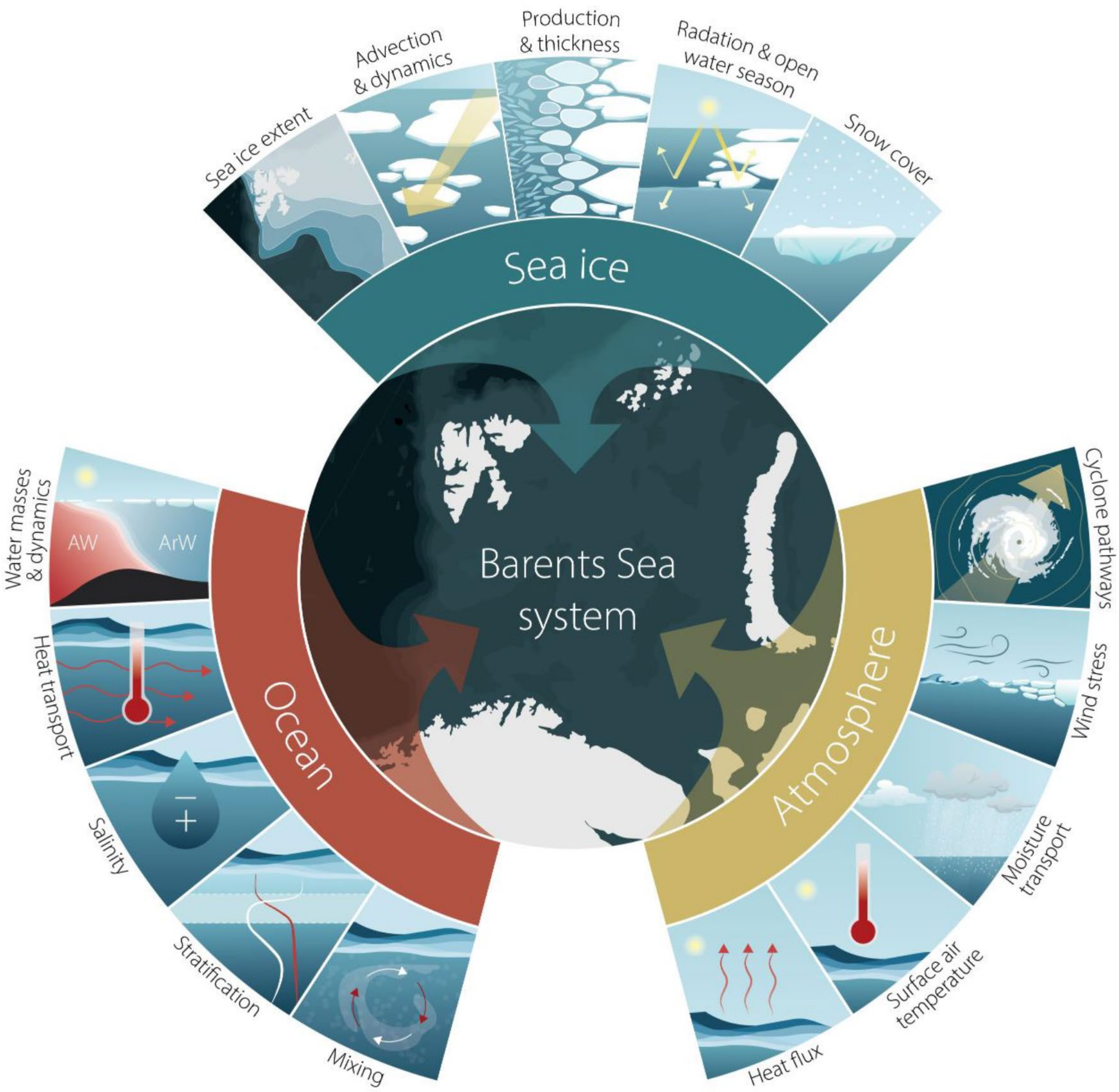


Illustration: Frida Cnossen

decade. Although the changes in water temperature and sea ice cover in the northern Barents Sea are monitored, year-round measurements of the ecosystem are still limited. Field observations from the winter months are especially rare, due to challenging weather and sea ice conditions. Over the recent years, the Nansen Legacy winter cruises have provided new insights into ocean and sea ice environmental characteristics, heat loss, CO_2 uptake, contaminant concentrations, food webs, and organisms' activity during the Polar night and the winter that increase our understanding of seasonal variations. The development of new technology for observations also in Arctic regions are promising, such as sea ice buoys, improved sampling routines and risk reduction for autonomous instruments. They will facilitate more observations in the future. Also international cooperation and coordination of observational strategies and platforms can support that physical and biogeochemical drivers will be better quantified in the future, and this will allow a more comprehensive understanding of ecosystem responses, connectivities, and complex feedback processes in the whole Arctic. ■

"The research on the development of the Barents Sea not only provides insights into the region's dynamics, but also points towards the need for improved understanding of climate change and its effects globally."

Sebastian Gerland, NPI

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Photo: Kay Jørgensen

Photo: Andreas Wolden

Increase of meltwater runoff on Svalbard affects fjords and coastal ecosystems

Svalbard has experienced Europe's steepest increase in air temperature over the past 60 years. Nansen Legacy researchers have now investigated how this warming has affected the glaciers on Svalbard by using high-resolution model simulations. The study revealed that between 1991 and 2022, mass losses by melting slightly exceeded mass gains by snowfall, but there is no clear trend due to large year-to-year variability. However, the meltwater runoff increased significantly.

Using model simulations to follow how glaciers react to warming climate

Nansen Legacy researchers used model simulations to see how the mass of glaciers on Svalbard and the meltwater runoff changed between 1991 and 2022. Since glaciers are huge and their meltwater runoff is difficult to monitor, model simulations represent useful tools to better understand how glaciers respond to the warming Arctic. The scientists found that results of two different forcing datasets corresponded quite well with each other and with field observations. These apparently reliable results are now publicly available at daily and monthly resolutions. It is suggested that model simulations could be continuously updated to make close-to-real time simulations of the runoff.

Changes in glacier mass and glacier runof

The model simulations reveal that the balance between snowfall and meltwater runoff of all glaciers on Svalbard declined only weakly between the year 1991 and 2022. However, different regions on Svalbard changed in different ways. While this decline was most prominent in the Atlantic-impacted southwestern parts of Svalbard, it is less pronounced in the more Arctic-influenced northeastern parts.

The model simulations also helped to follow changes in the runoff from the glaciers and from non-glaciated land on Svalbard. It was shown that both glacier runoff and the runoff generated by rain and snowmelt increased from 1991 to 2022. Since the glaciers on Svalbard are small compared to the Greenland ice sheet, their melting would only result in 15 mm rise of sea level. Nevertheless, the freshwater runoff can have a pronounced effect on the water circulation in Svalbard fjords and on productivity of the coastal marine ecosystems.

Effect of glacier runoff on the fjord ecosystem

Already in 2022, a Nansen Legacy scientist together with colleagues outside the project suggested that meltwater runoff stimulated the growth of planktonic microalgae for one decade between 2003 and 2013. This effect was restricted to fjords and the areas less than 10 km from the coast. With the now publicly available high-resolution model simulations of the Svalbard runoff over 31 years, more comprehensive and detailed investigations of the glacier runoff effect on fjords and coastal regions will be possible in the future. ■

"The simulations produced for this study are made publicly available on a daily and monthly resolution, and these [...] may be re-used in a wide range of applications including studies on glacial runoff, ocean currents, and ecosystems."

Louise Steffensen Schmidt, UiO

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Photo: Christian Morel/christianmorel.net

Mercury levels in the Arctic are increasing and vary with season

Many people know mercury for its use in old-fashioned thermometers. These thermometers are now banned because mercury is toxic and may cause serious problems to human health. But mercury also occurs naturally in the earth's crust. It is released into the environment and the Arctic is particularly prone to mercury pollution. Nansen Legacy researchers were the first to measure mercury levels in Arctic Ocean waters during winter.

Routes into the Arctic environment

Mercury can enter the environment via volcanic eruptions, forest fires, river runoff, and many other processes. The environmental behavior of mercury is presently affected by climate change. In the Arctic, for example, mercury is released from thawing permafrost and melting glaciers. The main release of mercury, however, is due to human activities, such as coal burning for heating and cooking, waste incineration, and industrial processes. Although these human activities are scarce in the Arctic, most mercury emission at lower latitudes evaporates to the air where it can persist in the atmosphere for over a year. This evaporated mercury can be carried by the wind to the Arctic. Due to this transport, mercury levels in the Arctic have increased by a factor of 10 in the last 150 years.

Bioaccumulation in the Arctic

Once in the environment, bacteria can transform inorganic mercury into the more toxic methylmercury. Methylmercury can be taken up by marine organisms via their diet and the contaminant biomagnifies in the food web. This means that lower concentrations are found in organisms at the base of the food web and higher concentrations found in top predators. Biomagnification happens because one large fish eats many contaminated small fish, and many large fish are eaten by one seal or whale. Although most species in the Arctic are at low risk for adverse health effects from mercury exposure, there are some geographic hotspots of high mercury exposure. Due to the transported mercury, the relatively long food web, and the fact that the indigenous people heavily rely on Arctic wildlife for their food supply, the people living in the Arctic are amongst the human populations with the highest mercury exposure on Earth. Monitoring mercury concentrations in this part of the world is therefore of great importance.

Seasonal mercury cycle in the Arctic

Stephen Kohler and his coworkers investigated the full seasonal cycle of both mercury and methylmercury in the Barents Sea. They found that the concentration of mercury was lower in winter than in summer, possibly because mercury sinks to the sea floor. The concentration of methylmercury, on the other hand, was lowest in spring and highest in autumn. Since the low concentration of methylmercury coincides with the spring bloom, a massive increase in phytoplankton abundance, the researchers speculated whether these two phenomena are linked. Potentially, phytoplankton could transform methylmercury back to the less toxic inorganic mercury. If this is true, phytoplankton would play an important role in decreasing the concentration of methylmercury in spring, potentially reducing the accumulation in the food web and the exposure to humans. This is good news and helps our understanding of natural and seasonal variability in contaminants. ■

> "The toxic pollutant mercury accumulates in marine food webs on a global scale, with consumption of seafood as the primary exposure pathway for humans."

Stephen Kohler, NTNU

Reference:
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Photo: Christian Morel/christianmorel.net

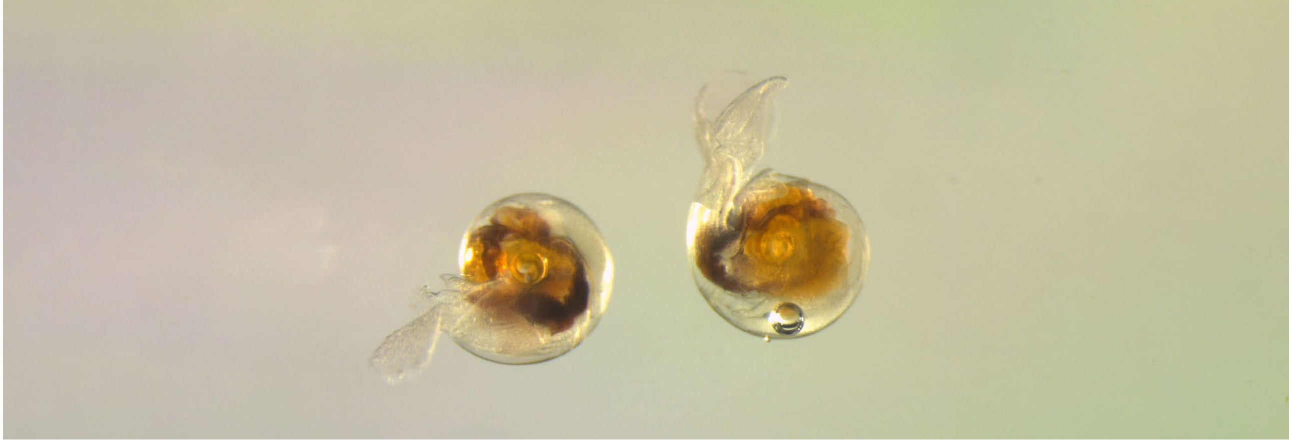

Photo: Snorre Flo

Ocean acidification in the Barents Sea

Human activities have contributed to more CO_2 in the atmosphere, driving climate change. The ocean has so far taken up about 30% of the anthropogenic CO_2 release. Since CO_2 dissolves best in very cold water, the CO_2 concentration in arctic waters has increased in recent years, increasing the ocean acidification. The state of ocean acidification in the Barents Sea and the effect on Arctic marine organisms has been studied by Nansen Legacy researchers.

The Barents Sea is a hotspot for ocean acidification as sea ice declines

Ocean acidification, known as "the equally evil twin of climate change", is occurring in all the world's oceans. The Arctic is particularly vulnerable for two reasons – it has cold water that can absorb more atmospheric CO_2, and the rapid loss of the sea ice, which is used to protect these waters like a semi-lid, increases the CO_2 uptake, especially in winter. The Barents Sea is one of the areas in the Arctic where sea-ice loss is most prominent. For the first time, Nansen Legacy members have studied the carbon cycle and state of ocean acidification in the Barents Sea across seasons, finding that it is an annual sink for CO_2. The most rapid change seems to be in the northern Barents Sea, where sea ice is rapidly declining and no longer effectively limiting CO_2 uptake into surface waters. Two separate studies emphasized that the risk of ocean acidification is intensifying in winter and early spring, as increases in surface CO_2 occur at twice the rate of atmospheric CO_2. This period coincides with the coldest surface water and, unfortunately, with the reproductive season of many planktonic communities, when they are most vulnerable to the effects of ocean acidification.

Ecosystem response to ocean acidification and warming – sea butterflies and Arctic copepods

Ocean acidification can be particularly harmful to shell-forming marine organisms and the early-life stages of other animals, such as key Arctic species. Some organisms produce shells made of calcium carbonate, which dissolves in water with altered carbonate chemistry due to ocean acidification. It is becoming increasingly difficult for them to form and maintain their shells. A thinner shell represents a weaker predator defense. The small free-swimming and shell-forming pteropods (winged snails called sea butterflies) play an important role in the transport of carbon from the surface to deeper layers and are thus important for the ocean's capacity to store CO_2. Nansen Legacy scientists found that these organisms were particularly abundant in the cold Arctic regions of the Barents Sea, where both sea ice loss and acidification are faster. They found the pteropod reproducing in winter and early spring, coinciding with the time of most intense acidification, so their future young may be particularly exposed. The predicted changes in Arctic marine ecosystems will not happen due to one stressor alone. Nansen Legacy researchers showed that ocean acidification alone does not seem to affect the small larvae of an important arctic crustacean, the copepod *Calanus hyperboreus.* However, effects were observed when the larvae were exposed to acidification combined with a warming scenario, as they needed more energy to survive. Studies like these improve our understanding of how human carbon emissions impact Arctic organisms and ecosystems and can help inform management practices and policies to protect the natural ecosystems. ■

> "Ocean acidification is speeding up in this already vulnerable area, with consequences for the planktonic communities"

Ylva Ericson, NPI

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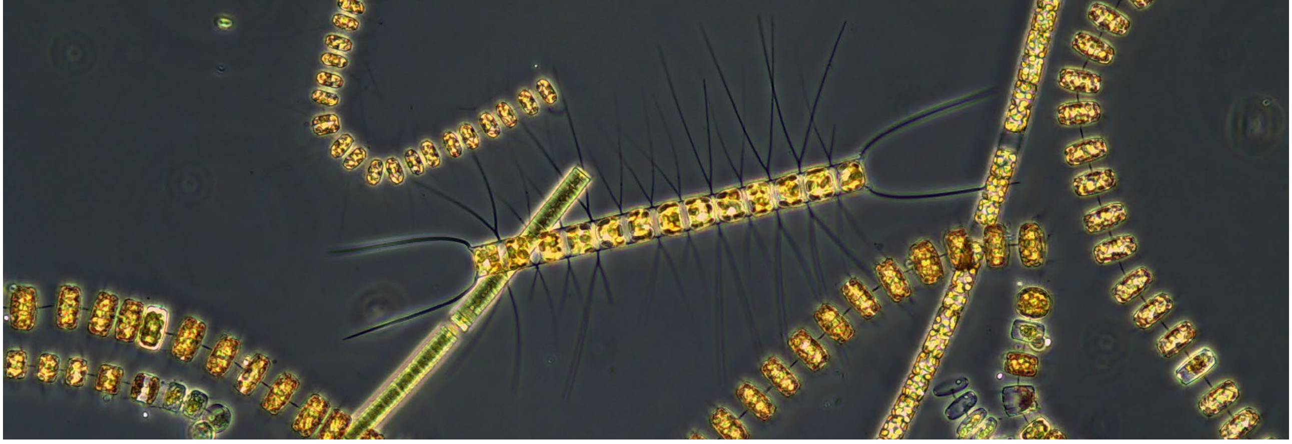

Photo: Snorre Flo

Local and distant events regulate the phytoplankton concentration in the Barents Sea

Plants in our homes and gardens need nutrients to thrive, and so does the 'grass of the ocean', the phytoplankton. When nutrients are available in the sunlit ocean surface, the phytoplankton production is high, and this is beneficial for the whole marine food chain. Nansen Legacy research revealed that the concentration of nutrients and phytoplankton in the Barents Sea can be predicted by events occurring thousands of kilometers away, or very locally, via pooping whales.

Phytoplankton: the base of the Arctic ecosystem

Phytoplankton, often referred to as the 'grass of the ocean', plays a crucial role in the Arctic ecosystem. Similar to grass, phytoplankton growth is regulated by sunlight and nutrients, and optimal conditions typically occur during spring. Longer days, particularly after the sea ice melts, provide ample sunlight, and surface nutrient concentrations tend to be high because vertical water mixing in the preceding winter replenished them. Under these conditions, phytoplankton production and biomass rapidly increase, leading to spring blooms. This phenomenon significantly enhances food availability for a short period in the entire Arctic ecosystem, including commercially harvested species.

Predicting phytoplankton abundance using historical data

Nansen Legacy researcher Filippa Fransner and co-workers examined the historical phytoplankton concentrations in the Barents Sea. A peak abundance event in the southern Barents Sea appeared to be linked to the inflow of extraordinary nutrient-rich Atlantic Water. Modelling simulations indicated that this nutrient-rich water had formed five years earlier in the North Atlantic and travelled northward along the Norwegian coast to the Barents Sea. This finding illustrates that events that happened in the past and far away from the Arctic, can affect the phytoplankton abundance in the Barents Sea today. In other words, Fransner's work suggests that events happening today, can help to make predictions of the Arctic ecosystem in the future.

Regulating phytoplankton abundance with locally produced whale poop

In addition, there are also very local and not so obvious nutrient sources for phytoplankton, for example in the form of minke whale poo. On average, one minke whale produces 40 kg of nutrient-rich excrements per day. Nansen Legacy scientists Martin Biuw and Tore Haug, together with others, calculated that the minke whale poo in a small management area of Svalbard may contribute to 0.2 to 4% of the daily primary production in that region. The two studies above highlight that phytoplankton production and concentration can be regulated both through local and distant events. This suggests that accurate predictions for the future do not only model simulations of large-scale processes, but also ecosystem understanding of local species interactions, such as whales and phytoplankton. ■

> "The skilful prediction of the phytoplankton abundance is an important step forward in the development of numerical ecosystem predictions of the Barents Sea."

Filippa Fransner, UiB

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A year in the life of the northern Barents Sea

The changing of the seasons is the most important driver of the cycles of life and of climate on the globe. Nowhere is this more prominent than at the poles, where extreme seasonality occurs. Still, most knowledge is based on summer observations, while conditions during the remaining part of the year have been based on reasonable or not so reasonable assumptions. A new special issue on seasonality closes some of these gaps for the northern Barents Sea.

The Barents Sea is one of Norway's most important fishing grounds, with fish, shrimp and crab fisheries, but this shelf sea also experiences dramatic changes due to human-made climate change and pollution. Especially the northern Barents Sea has changed over the last two decades, but the understanding of its ecosystem has mainly been based on studies conducted during the summer months, when access to the remote and otherwise ice-covered area is easier. To fill some of the knowledge gaps and gain a year-round system understanding, the Nansen Legacy conducted five field campaigns with the ice breaker *Kronprins Haakon* to the Barents Sea in August and December 2019, and March, May, and July 2021. In addition, scientific moorings filled with sensors and sampling devices were deployed to fill the temporal gaps between the ship-based investigations, and to capture the full annual cycles. The results from this work are now available in a special collection of scientific articles in the journal ***Progress in Oceanography.***

The publications provide a new, detailed understanding of, among others, the seasonality of water properties, ocean currents, ocean chemistry, and biological processes, and highlights are provided below.

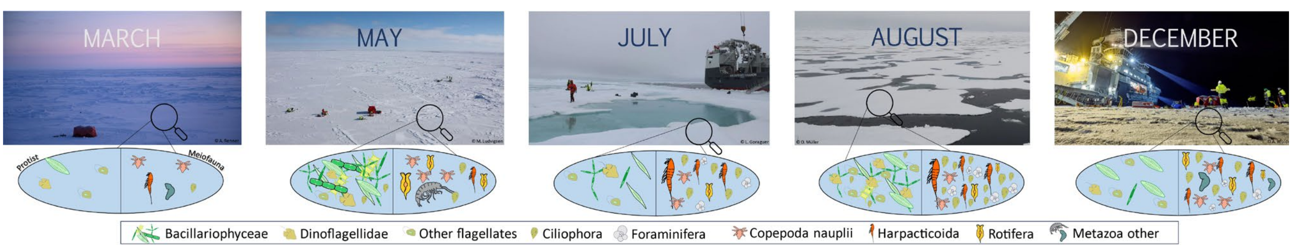
"Questions on the magnitude of seasonal variability of important processes and ecosystem components still remain for the northern, Arctic areas of the Barents Sea. Some of those knowledge gaps we attempt to address in this issue"

Bodil Bluhm, UiT, editor

Unlike ice cubes in a drink, sea ice is never a compact block of ice. If you were to look really closely into the sea ice, you would see that it is not only made of lots of tiny channels and spaces, but that these are filled with life. Ice algae reside here in spring, and as the season progresses, tiny animals (called meiofauna) take over. Surprisingly, there also seems to be many active ice dwellers in the winter, highlighting the winter as more important for these habitats than previously expected (**Marquardt et al. 2023**).

Life below the surface waits for the light to return in spring, but conditions must be right. Sea ice, polar surface water and winds can greatly influence the amount of nutrients that are available in the surface waters and are crucial for phytoplankton blooms. After a large spring bloom, these conditions do not allow for early enough resupply of nutrients in the area north of Svalbard for a possible second bloom in the autumn (**Renner et al. 2023**). The Barents Sea is also a place where the warm nutrient-rich Atlantic water meets the cold polar water at the Polar Front, and now we know that up to a quarter of the nutrients replenished to the Barents Sea surface each winter may be supplied by mixing during winter storms (**Koenig et al. 2023**).

It has also been found that zooplankton arrive in seasonal pulses with the inflow of Atlantic water into the Barents Sea. During summer, Atlantic species dominated south of the Polar Front, while Arctic species were prominent to the north throughout the year (**Wold et al. 2023**). Zooplankton feeding strategies were observed to shift with the seasons too, with mainly herbivory in summer and carnivory in winter when less fresh algal food is available (**van Engeland et al. 2023**). Echosounding data further revealed that communities with large zooplankton (<2 mm in size) were present throughout the year and could be found in a thick layer within Atlantic core water in the northern shelf slope of the Barents Sea. Some of these large zooplankton were even observed to perform daily vertical migrations up and down in the water column throughout the polar night, although they mostly do this in the transition period between the polar night and midnight sun (**Cannaby et al. 2023**).



Marquardt et al. 2023

Photo: Andreas Wolden

Despite the changing in sea ice conditions in the northeastern Barents Sea in the past decades, no long-term trends of increasing or decreasing primary production were observed between 1980 and 2021, neither in observational data and model output (**Castro de la Guardia et al. 2023**). However, observations from August 2018 and 2019 suggest that earlier sea ice melt leads to different communities of phytoplankton and other single-celled organisms in the summertime Barents Sea compared to years with later ice melt. This could mean a shift in the food chain, where a long summer productive season may not favor higher trophic levels, such as fish and birds, but instead go on to feed the microbial community (**Kohlbach et al. 2023**). The microbial communities, including bacteria and archaea, can adapt to seasonal changes in these primary producers and during the summers of 2018, 2019, and 2022, the same groups dominated but varied in abundance depending on food availability (**Thiele et al. 2023**).

The upper sunlit waters produce most of the food (organic matter) for the oceans ecosystems and sets the framework for how much CO_2 can be transferred to the deep for long-term storage. The deeper the organic matter sinks after its production, the more likely it is that the carbon is stored for a long time. However, it has now been shown that seasonality in the upper waters determines how deep organic matter sinks and that also the composition of the sinking matter differs in spring and summer (**Bodur et al. 2023**). Despite a pronounced seasonality in the quantity and quality of the sinking matter, the amount and structure of bottom dwelling organisms did virtually not change with season (**Jordá-Molina et al. 2023**). Further, trophic structure of the bottom dwellers remained essentially the same across seasons as well, although the food quality in the sediment lagged approximately 6 months behind the spring bloom, with the highest quality during late summer and winter (**Ziegler et al. 2023**). The organisms living on the sea floor may, therefore, experience the pronounced seasonality in the Arctic to a much lesser degree than their counterparts in the water column and sea ice.

The collection of new seasonal knowledge provided by the Nansen Legacy team is a large step forward to understanding this highly seasonal and dynamic area better, and more studies on this topic have been or are to be published in 2024. Many of the findings highlight that there is far more biological activity taking place during the polar night and the winter periods than previously known, often connected with the strong advection of warm Atlantic water into the region during this time. This has implications for our understanding of the Arctic ecosystem and is crucial for the management and risk assessments of human activities in the Barents Sea during winter. ■

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Glimpses of the Nansen Legacy knowledge production 2023

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

- Populations of Arctic copepods **increase their biomass 5 times during the growth season** and **prolong their development time** if spread to colder Arctic waters by ocean currents, according to results from an individual-based model. Aarflot et al. 2023
- **Key Arctic copepod** species have **flexible metabolic rates in winter**. The highest rates were seen in opportunistic feeders, allowing them to **adapt to scarce food availability in winter**. Karlson et al. 2023
- Long-term data from the Barents Sea revealed that large copepods searched darkness and dwelled **deeper in ocean areas without sea ice cover** and were absent in shallow areas. This supports the idea that these organisms try to avoid visual predators. Langbehn et al. 2023
- **Energy reserves** in the Arctic zooplankton groups krill and amphipods **differ across seasons**, and they also vary with species, sizes, and needs for stored reserves in winter. Nowicki et al. 2023
- Only a few pelagic organisms were observed in the Central Arctic Ocean in summer, but with **distinct and different communities within the Nansen and the Amundsen Basins**. Ingvaldsen et al. 2023
- During very cold conditions, **unique frost flowers** form on newly frozen sea surfaces. The first study on their bacterial and archaeal community composition revealed **specific bacteria communities** that suggest active sulphur and nitrogen cycling in these short-lived structures. Thiele et al. 2023
- Green, red, and brown **macroalgae grow in winter and were healthier during the polar night** compared to the end of the light season. Summers et al. 2023

Hydrography and sea ice

- Year-long observations of current velocity on the continental slope north of Svalbard showed evidence for **super-inertial internal waves that can reach an amplitude of 4 cm s^{-1}**. Baumann et al. 2023
- Atmospheric wind patterns influence warm water inflows from the North Atlantic. This large-scale weather pattern **impacts ocean circulation, freshwater transfer, and heat fluxes**, potentially accelerating sea ice loss and altering the Arctic climate system. Polyakov et al. 2023
- Regional weather and climate are impacted by jet streams. A framework to distinguish subtropical jets from eddy-driven jets reveals the **role of the different jet stream types for different ocean basins**. Spensberger et al. 2023
- The **Atlantic water inflow to the Arctic Basin is intensified in winter** and located near the surface according to year-round observations from moorings on the southern slope of the Yermak plateau. The total **volume** of transported Atlantic Water **is highest in fall and lowest in summer** Fer et al. 2023
- Sea ice ridges form when sea ice fragments collide and are pressed against each other. Two first-year ice ridges were studied and **6-11% of the total ice mass on first-year ice ridges was found to be consolidated snow meltwater**. This affects ice volume and ridge strength, with implications for habitat, light levels, and shipping access. Lange et al. 2023

Environmental stressors: pollution, warming and sea-ice loss

➢ **A poleward distribution shift of species in warm versus cold years** was predicted by a new dynamic spatial food web model, including species' habitat requirements and ecological interactions. Nascimento et al. 2023

➢ Exposure to crude oil affected the **spawning likelihood, gene expression, and egg pollution level in polar cod**. A review predicts **habitat loss and reduced biomass for polar cod, and potential negative impacts on its predators** in the face of climate change. Strople et al. 2023, Geoffroy et al. 2023

➢ An opinion piece highlights the importance of winter and the **need to understand how winter affects ecosystems.** The need for more research on the **effects of human activity and multiple stressors during winter** is emphasized to better manage and conserve ecosystems in a changing climate. Dinh et al. 2023

➢ Arctic warming and sea-ice decline are linked to cooling over Eurasia, but the causes are still debated. A review proposes that **both internal variability and sea-ice retreat play central roles**, offering a nuanced understanding of Eurasian cooling in the context of ongoing global warming. Outten et al. 2023

➢ A **warm water event** in the arctic Rijpfjorden on Svalbard **in 2006, caused a significant drop in species and individuals living on the sea floor**. The communities **recovered by 2010**, but prolonged warm water could permanently change these ecosystems. Jordà-Molina et al. 2023

Technology and Method Development

➢ **New ocean-sea ice coupled models** were developed to study multi-year sea ice in the Arctic. The modeled values **match satellite observations**, remain within the estimated uncertainty, and are beneficial to use alongside satellite observations. Boutin et al. 2023, Regan et al. 2023

➢ A new method identifies the **relative role of natural versus forced (human) induced sea-ice variability**. Forced variability is more important than most models suggest, and most prominent in the Barents- and Kara Sea region, while natural variability explains most decadal trends in the Bering Sea region. Dörr et al. 2023

➢ **A new design** for low-cost lightweight **uncrewed aerial vehicles** for remote sensing purposes is presented. It **allows for reflectance computation for different lighting and atmospheric conditions**. Hasler et al. 2023

➢ Autonomous marine systems are unmanned marine vehicles, which can pose challenges in maintenance, planning, and execution during a voyage**.** **A maintenance strategy for these systems has been proposed**, with a framework for online risk modeling. Yang et al. 2023, Yang et al. 2023

➢ A study from the northern Barens Sea found that **phytoplankton drive the changes observed when measuring the absorption of light by particles** in the water column. A method was developed to estimate the biological parameters of particulate organic carbon and chlorophyll *a,* using light attenuation and fluorescence. Sandven et al. 2023

Photo: Robin Hjertenes

Modelling approaches in the Nansen Legacy

An overview of our model approaches

The Nansen Legacy researchers have used and combined a range of different models. The models are specialized to represent and explore different compartments relevant to the ocean and ecosystems. They help us to zoom in and out in time and space and integrate our often fragmented understanding of specific processes or compartments.

Model approaches

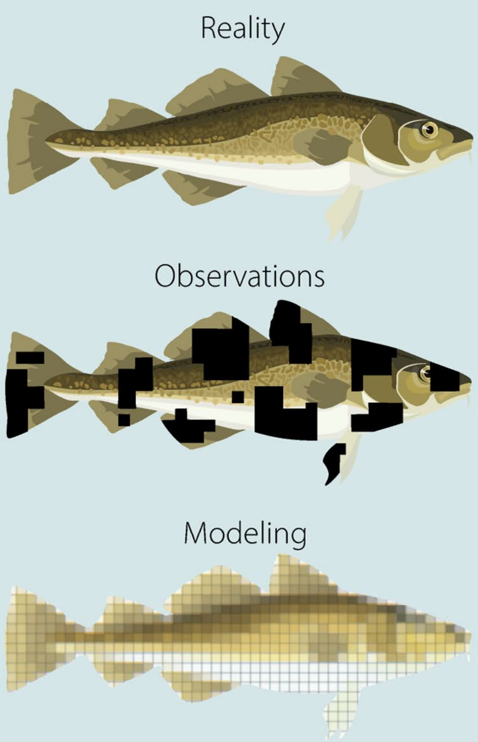
The >20 different models used by the Nansen Legacy community represent a complementary approach to field observations, focusing on different parts of nature and impacts of human activities. The models comprise a complementary and wide specter of tools that help us understand the complex processes in the ocean in better detail, either in combination or as a part of a larger global system. This can, for example, be how fractures in sea ice, on a small scale, can be translate to large scale impact on weather conditions, or how global features like climate warming act on regional scales like heat transport with ocean currents and how this can influence sea ice formation. Coupled physical-biological models can help us understand how increased ocean temperatures impact changes in growth or survival of specific species in the ecosystem, and the cascading impact on other species and the system as a whole. By understanding present global and local conditions, models help us to reconstruct the past, and forecast, predict, or project possible future scenarios on shorter or longer time scales.

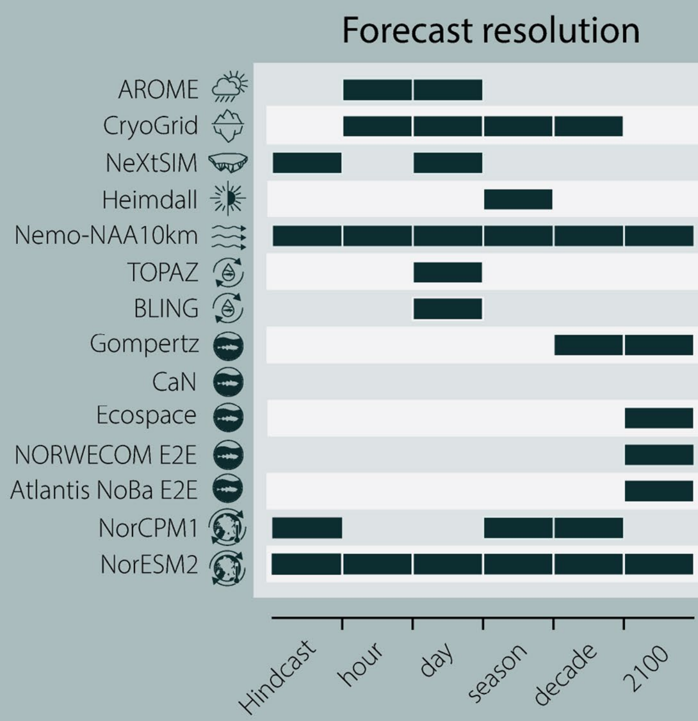
Different models address different scales and complexities

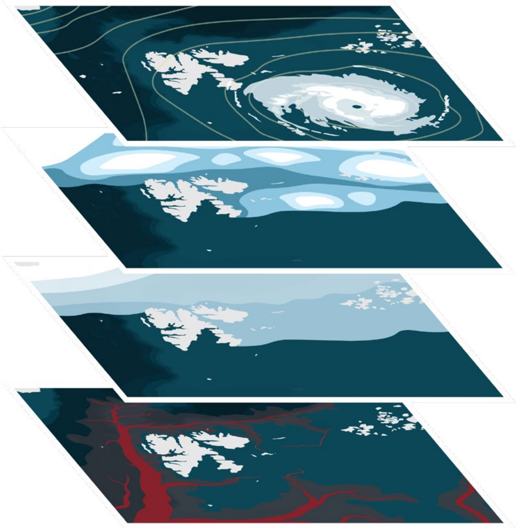
The cost of running a model depends on the complexity and resolution of the model. End-to-end (E2E) ecosystem models driven by physical models of intermediate spatial resolutions requires huge amounts of computational time and storage space. Models that explore the possible outcomes of interactions among selected key ecosystem species on the other hand, are much simpler models that can be run thousands of times to identify the specter of possible outcomes. Some models focus on smaller regions, and shorter time spans, like weather forecasts, while others include global processes and make projections for several decades in the future, like the NorESM model (Norwegian Earth System Model). None of the models can answer all questions, so it is important to use the type of model that best represents the specific questions we ask.

What is a model?

A model is a tool to aid in closing gaps in our observations and understanding. With fragmented pieces from field observation, experiments, and general knowledge the models can help to zoom out to a larger picture and a longer time scale to provide a more complete understanding of a system like the Barents Sea.

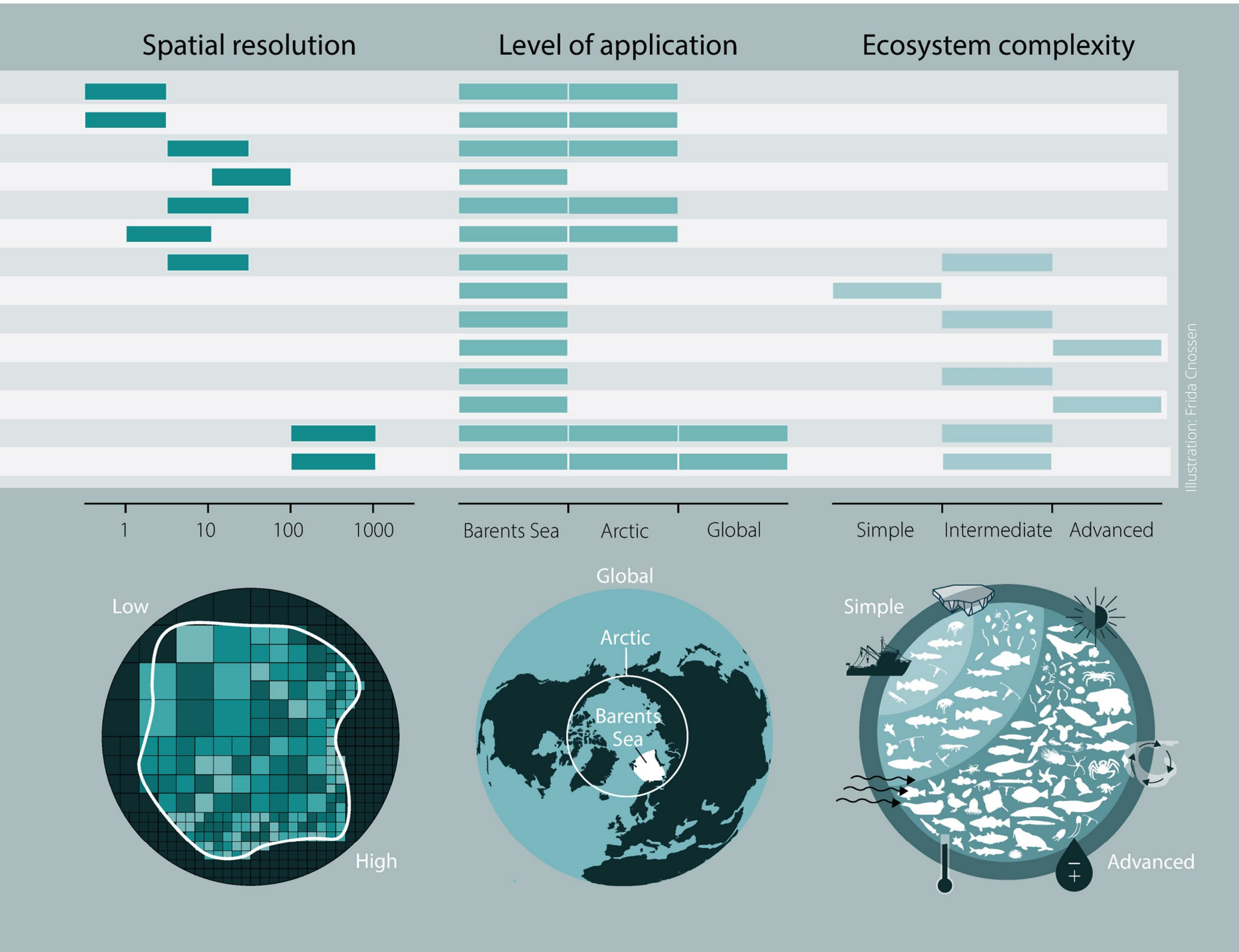


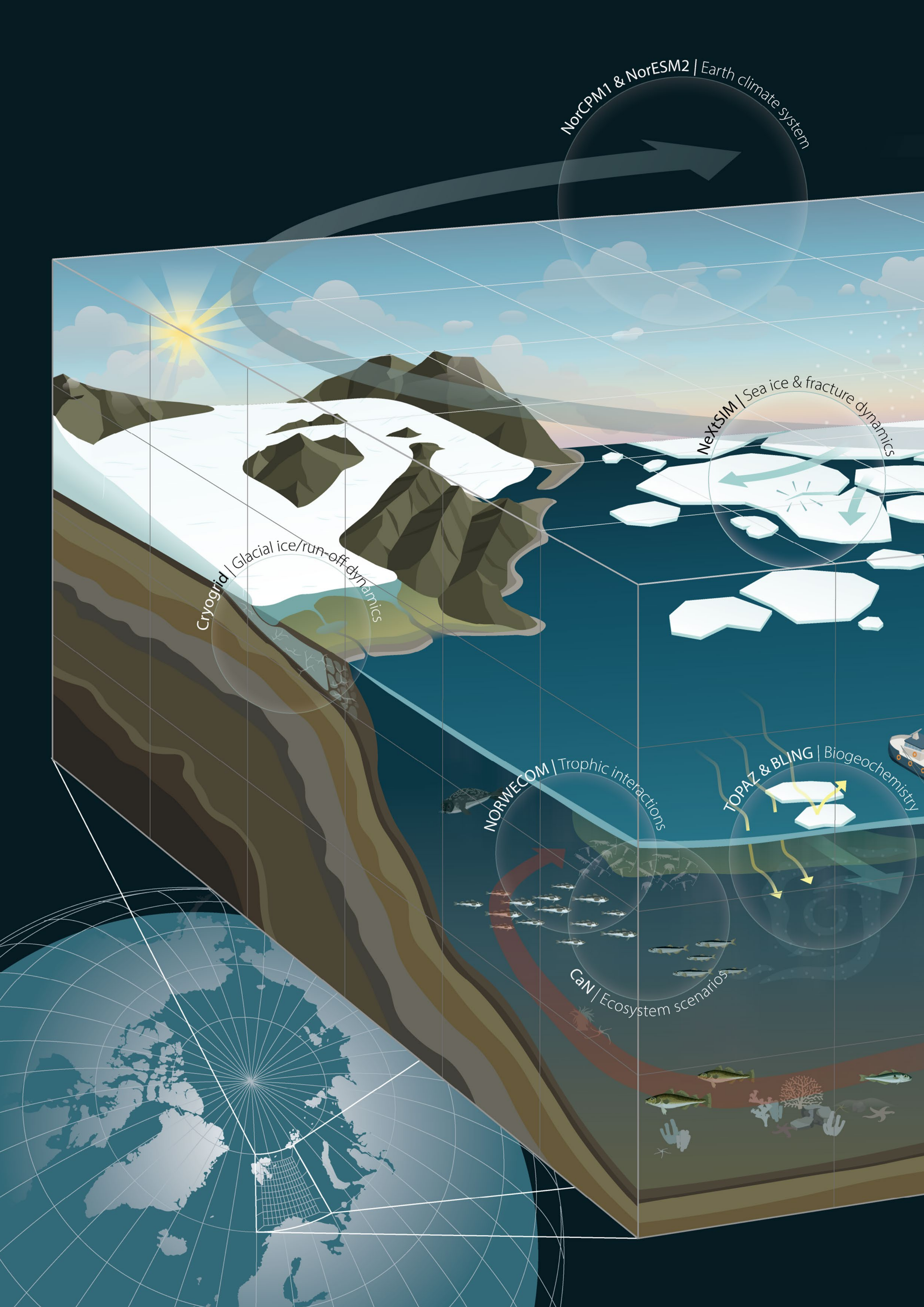


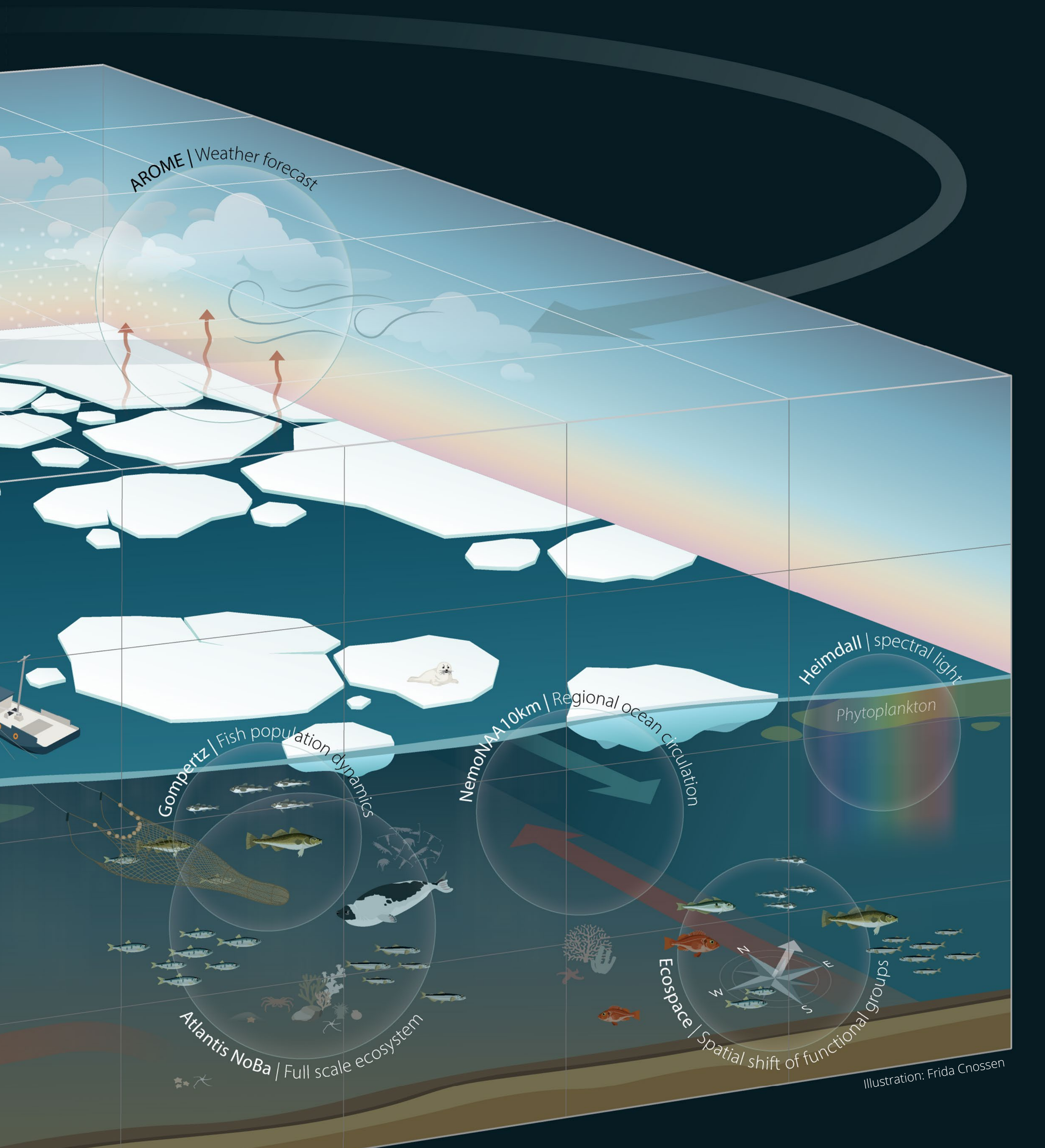


Improved tools with combined models

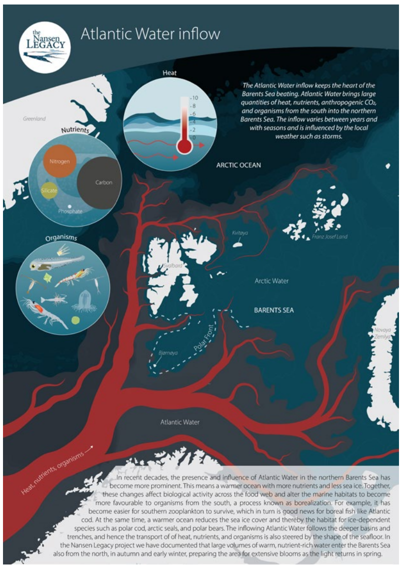
In the Nansen Legacy project, model work has both focused on improvement of specific models, but also on how we can combine individual models. When we combine our understanding of the ocean, the sea ice and snow, waves, and the atmosphere through model stacking, we can improve the accuracy of weather-, sea ice- and wave predictions. Combining models is however not a simple addition of specialized models, but a considerable effort in making sure that the integration keeps the quality of each model, and in addition, provides an integrated reliable result that can be evaluated against observational data. Also the climate projections made by the global climate models represent valuable outputs that have been fed into biogeochemistry and ecosystem models to give us projections and scenarios of the future Barents Sea. One of the key findings from these projections is that the response time in the Barents Sea climate and ecosystem is so long that changes we make now with respect to carbon emissions will not be seen as responses in 2050, but will make a huge impact in 2100. ■

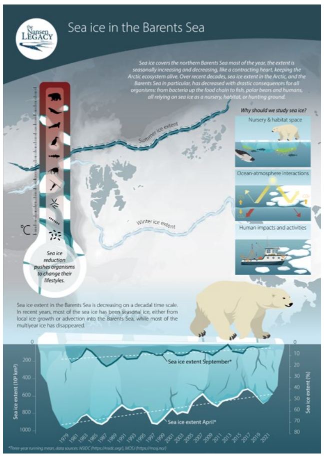


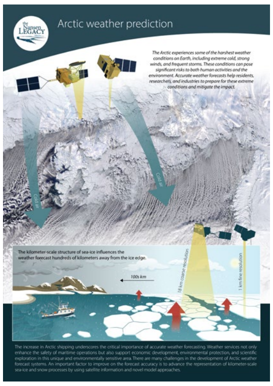

NorCPM1 & NorESM2 | Earth climate system
NeXtSIM | Sea ice & fracture dynamics
Cryogrid | Glacial ice/run-off dynamics
NORWECOM | Trophic interactions
TOPAZ & BLING | Biogeochemistry
CaN | Ecosystem scenarios

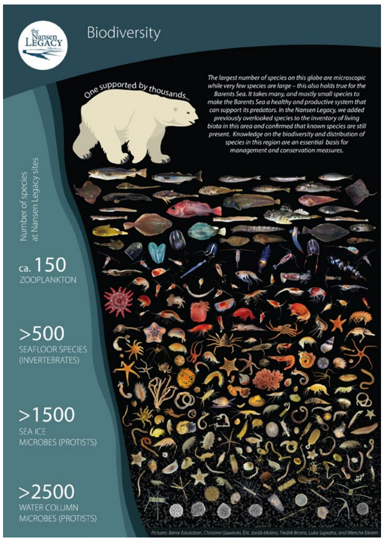


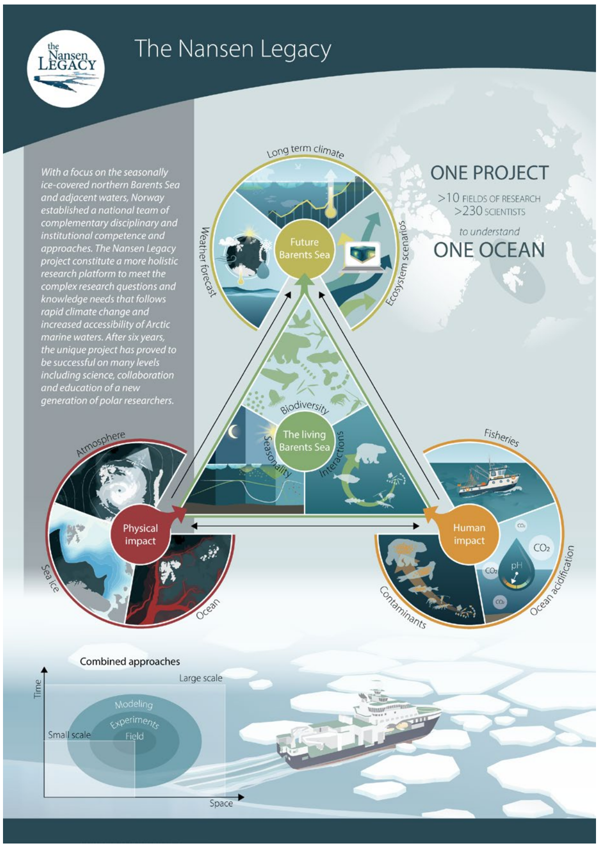
Models represent compartments of the natural system on different temporal and spatial scales. Some of the models used by the Nansen Legacy researchers are shown as spheres with names and functions. They are distributed in the Arctic marine environment to illustrate how they are used to explore parts of the climate and ecosystem, alone or in combination.

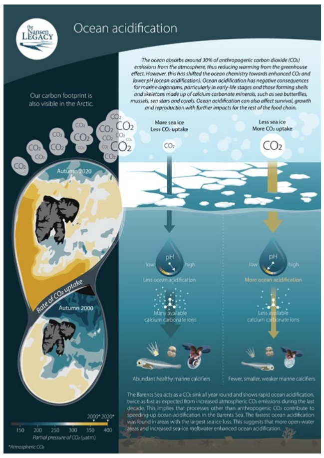


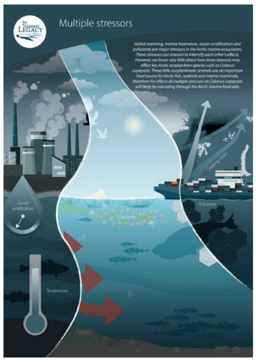


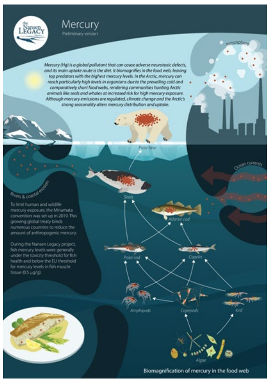


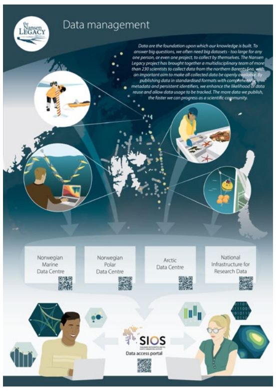


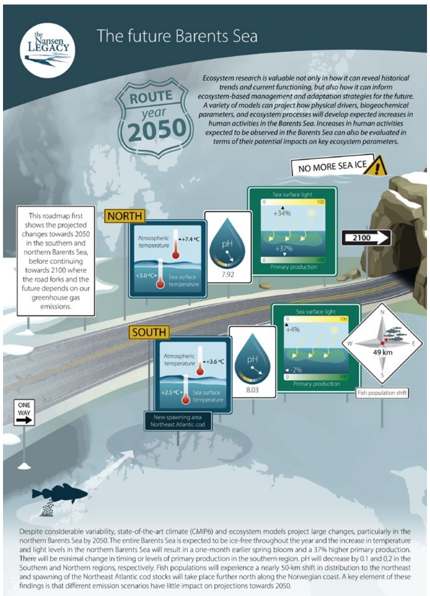












The fact sheets can be found here

The Barents Sea seen through illustrated fact sheets

A picture can tell more than thousand words, is a well-known statement, and we fully agree. Nansen Legacy researchers teamed up with a science illustrator and produced ten fact sheets. They feature descriptive and vivid graphics that, combined with informative text, effectively draw attention, and communicate the project's key findings in the Barents Sea.

Ten beautifully illustrated fact sheets on Nansen Legacy key research themes were released during the international symposium organized by the project in November 2023. The fact sheet themes span from improved weather forecasts, the impact of the Atlantic Water current on the Barents Sea environment and ecosystem, sea ice characteristics and its associated ecosystem, biodiversity, ocean acidification, and contaminants, to outlooks for the future Barents Sea. This innovative way to share findings of a science project has received much praise and inspired an internationally community of colleagues. The fact sheets are, however, more than a tool to communicate findings to the society. Assembling them also served as a valuable tool for the internal integration of results inside the Nansen Legacy.

Photo: Lars Olav Sparboe

When the Nansen Legacy project entered the phase where synthesis and integration of results topped the agenda, we asked: How can results across the different research disciplines, institutions, and activities best be integrated? And how can the key findings and important information about the Barents Sea, about how it is impacted by natural variability and a changing climate, and about increased human impact, be effectively communicated to user groups and a broader public?

Task force groups were formed to focus on collectively identified central themes. Besides organizing sessions during scientific conferences or producing synthesis articles, each task force group was asked to condense key findings into one fact sheet. During workshops and dedicated sessions during the project's annual meetings, Nansen Legacy scientists across disciplines, institutions, and career stages joined forces. First, they integrated their respective results and understanding, and then condensed the essential information into short take home messages. These ideas were in the next step discussed with science illustrator Frida Cnossen (see separate story on page 52-53) to identify the best way to communicate the core messages through illustrations and text. Users and stakeholders from our reference group provided valuable input to improve the drafts.

The transformation from scientific ideas to informative and exquisitely illustrated fact sheets also inspired other Nansen Legacy scientists and thus the list of fact sheets became longer than originally planned. Presently, ten fact sheets from the Nansen Legacy research are published, and a few more are underway. The process and products demonstrate how complementary competences across disciplines combined with a great talent for visual expressions can integrate and translate science results in an appealing and understandable language. New knowledge and important messages about the present and future Barents Sea can in this way be channeled to policy makers, stakeholders, users, science colleagues, and the general public. ■

Placing the Nansen Legacy results in a pan-Arctic context

The international and interdisciplinary science symposium "Towards the new Arctic Ocean – past, present, future" hosted by the Nansen Legacy, marked the final phase of the project. Nansen Legacy results were placed in a pan-Arctic context to connect and discuss the current understanding of the arctic climate- and ecosystem and to link scientific observations to the process of knowledge adaptation.

Photo: Frida Cnossen

Nansen Legacy in the pan-Arctic context

Over the past 6 years, Nansen Legacy researchers have studied processes in the northern Barents Sea and the adjacent Arctic Ocean. To place the new understanding of this region in a pan-Arctic context, the project invited the international research community to Tromsø for a three-day international symposium entitled "Towards the new Arctic Ocean – past, present, future". The main objective of this meeting was to integrate scientific findings from the Nansen Legacy project with the current understanding of climate- and ecosystem functioning in other arctic regions. The symposium also discussed how scientific observations could help arctic societies to adapt to a changing Arctic.

A varied program stretching from observation to adaptation

International keynote speakers and Nansen Legacy experts discussed central topics such as changes in the inflow of the Atlantic water, the impact of freshwater runoff, and the future of arctic sea ice in the keynote talks. These discussions were complemented by expert sessions focusing on oceanography, biogeochemistry, marine biology and geology, and different arctic regions. Many early career researchers presented their scientific findings during these parallel sessions.

In addition to the scientific program, a side event was organized in collaboration with the EU project Arctic Passion and with support from the Norwegian Arctic Council chairship. This half-day event shed light on how a good coordination of different observing systems in the Arctic can provide strategies and solutions to local coastal communities and international resource management, facilitating adaptation to the new, seasonally ice-free Arctic. Experts in the panel were, among others, Øystein Hov, former Research Director of the Norwegian Meteorological Institute, Camilla Brattland, Associate Professor in Samí Cultural Science at UiT The Arctic University of Norway, Alan Haynie, General Secretary of ICES, and Marianne Kroglund, Senior Advisor at the Norwegian Environmental Directorate in Norway.

An international team of helping hands

The symposium was planned and organized by a large team, including Nansen Legacy early career researchers and senior scientists, international experts, the project administration, and members of the reference group. Photographer Christian Morel developed a picture exhibition for the lobby of the meeting venue, showcasing Nansen Legacy fieldwork to tourists, Tromsø locals, and symposium participants. Approximately 260 researchers from 18 countries, only half of them associated with the Nansen Legacy project, contributed to the success of the meeting in early November 2023. ■

Photo: Christian Morel/christianmorel.net

Synthesizing knowledge in workshops

The process of integrating results across cruises, approaches and disciplines, and to get data published requires dedicated time and collaboration. Seven workshops were organised by Nansen Legacy members in 2023 to facilitate and speed up this work. The workshops were successful and included senior scientists and early career researchers, Nansen Legacy members and collaborating partners.

Workshops to write synthesis papers

Several task force groups on key topics addressed by Nansen Legacy were initiated in 2022. Writing review articles to synthesize knowledge from different individual scientific studies within the Nansen Legacy project was a goal set by some of the groups. Workshops were organised to discuss and write these works.

The Atlantic Water Inflow Task Force Writing Workshop
The inflow of warm and salty Atlantic Water into the colder and fresher Arctic Ocean can have consequences for the global climate system and the Arctic ecosystem. The Atlantic Water Inflow task force group aims to explain which factors influence the inflow of Atlantic Water, and to provide a better understanding of the transportation and redistribution of nutrients, carbon, plankton, and pollution via different currents in the Barents Sea. Knowledge on this topic, produced by different scientist within the Nansen Legacy project, is now being reviewed in one synthesis article. The writing process was initiated with a workshop in April 2023 where the authors made an outline, refined the scope of the manuscript, and planned the writing process. The manuscript will be finalised in 2024.

The Barents Sea 2050 Task Force Writing Workshop
The marine ecosystem in the Barents Sea is responding rapidly to the changing climate. Changes like increased air- and seawater temperatures, thinner and reduced summer sea ice, changed pathways, and organisms responses to contaminants and multiple stressors can have consequences for the ecosystem. These changes can affect food- and job security in Norway and the rest of the world. During the Nansen Legacy project, researchers from different disciplines have gathered data and worked with model simulations to predict changes in the Barents Sea's ecosystem, physical environment, food webs, contaminants and biogeochemistry. The different model predictions are collected in one synthesis article to provide scenarios for 2050 and 2100. The authors started the writing during a workshop early this autumn. The workshop initiated a successful process, and a first draft was ready by the end of 2023.

"It was very useful to get people to talk directly. A lot gets lost in email."

Bodil Bluhm, UiT

Workshops to share and discuss scientific data

Estimating annual production of different trophic levels in the Barents Sea workshop

In the past years, Nansen Legacy scientists have estimated the seasonal production of different levels of the Barents Sea food web using different methods, including experimental and satellite data, as well as modelling results. During this workshop, scientists brought their data and compared their production values across approaches to agree on the best method to estimate the total annual production. Furthermore, they gathered production estimates of different levels of the marine food web, including bacteria, plankton, and fish, to gain a better understanding of the production of the whole Barents Sea ecosystem. This is an important step forward in the work of the Nansen Legacy project, which set out, among other things, to estimate the range of total annual production along environmental and spatial gradients.

Benthic biodiversity and carbon cycling workshop

The bottom of the sea is a largely unexplored area since it is a difficult place to reach. Organisms living in and on the seafloor are called benthic organisms. To improve our understanding of the benthic biodiversity, researchers from the Nansen Legacy project, as well as key scientists outside the project, came together at this workshop to compare the carbon cycling of benthic organisms in the Barents Sea, which is on average 230 m deep and thus relatively shallow compared to the Nansen Basin in the central Arctic Ocean with an average depth of 3700 m. This comparison was made using carbon demand estimates from body size measurements combined and the oxygen consumption of the organisms. In addition, a plan was made to publish articles discussing the meiofauna (small animals such as tiny worms), and macrofauna, (larger animals such as mussels) in the Barents Sea and Nansen Basin.

Second underwater hyperspectral imaging (UHI) workshop

A hyperspectral image is an image where a wide spectrum of light has been analysed, while in a regular image only red, green, and blue pixels are analysed. Underwater hyperspectral imaging is a useful technique to provide data on phytoplankton and ice algal biomass and biodiversity, photosynthesis rates, coloured dissolved organic matter, and data on many other underwater processes. During the UHI workshop researchers came together to start the production of a synthesis article, in which activities from the Nansen Legacy project and the MOSAiC project will be compared and synchronized. The synthesis paper will be an important contribution to the development of new innovations to enable technology in marine ecology and physics studies in the Nansen Legacy project and future projects. ■

Workshops to publish acquired scientific data

Bring and Publish your Data

The data manager of the Nansen Legacy project, Luke Marsden, organized two workshops in 2023 to help Nansen Legacy scientists to organise, standardise and publish their data. One workshop was organized in collaboration with the Global Biodiversity Information Facility (GBIF) and focused on publishing datasets related to biodiversity. The abundance of all kinds of organisms at a specific location during a specific time is thus made available for a global community. These organisms can be anything from big whales or microalgae in the water to tiny critters in the sea ice or at the sea floor. The data were transferred in the so-called Darwin Core data format and published publicly available through the GBIF data base. Luke Marsden's second workshop was centred around the data format NetCDF. This format stores information on for example water temperature or nutrient concentrations together with the location, time, sampling depths, and other central information which is key for other scientists to re-use the data later on. All NetCDF data are now publicly available through SIOS Svalbard. In line with these workshops, the number of published datasets and the proportion of datasets that adhere to the projects data policy and data management plan substantially increased this year compared to previous years.

Photo: Mathias Molvik

Photo: Robin Hjertenes

Career pathways of the Nansen Legacy early career scientists

The Nansen Legacy was over the last 6 years home to over 120 early career scientists, including master's students, Ph.D. candidates, and postdoctoral researchers. 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. In return, the Nansen Legacy supports these early career scientists increased research opportunities in a larger research community and valuable experience for their future careers.

Silje Mortensen is from the small village Myre in the archipelago Vesterålen, Northern Norway. As a master's student in the Nansen Legacy, she utilized ecosystem modeling to understand how a higher water temperature and krill fisheries could impact the catch of commercially used fish species in the Barents Sea. Upon graduating from UiT in 2023, Silje became an advisor in the organisation "Sør-Norges Fiskarlag". This is a subsection of the organisation "Norges Fiskarlag" that works for both fishermen and employers in fishing industry. Silje's still young career illustrates how modelling experience and ecosystem understanding can help in a later profession to balance economic growth in fisheries and sustainable utilization of the marine ecosystem.

Marius F. Maurstad experienced the Arctic for the first time when he joined the research cruises to the northern Barents Sea aboard the icebreaker *Kronprins Haakon*. At that time, Marius was a master's student in the Nansen Legacy, investigating the historical and contemporary hybridization between the two species, Arctic and Polar Cod. Apart from contributing to the overarching goals of the Nansen Legacy, the early-career scientist gained substantial knowledge in genome sequencing, population genetics, and bioinformatics through the project. Equipped with this skill set, Marius was well-prepared to advance his scientific journey. In 2023, he started in a Ph.D. position the Centre for Ecological and Evolutionary Synthesis at UiO. Although Marius's current focus is on the evolution of insect venom, which is not directly related to the Arctic, the transferrable skills he acquired during his time with the Nansen Legacy remain crucial in his current position.

Johanne Skrefsrud is a Ph.D. candidate at the Geophysical Institute at UiB. She is part of the team working on the topic "The Future Barents Sea", and her specific focus is on ocean circulation and heat transport in the North Atlantic. Johanne combines observations with modeling to understand how ocean currents transport water masses and heat. However, it is not only Johanne's scientific work connecting the Caribbean, the North Atlantic, and the high North. She is also an enthusiastic teacher who enjoys sharing her knowledge with school kids in both Bergen and the Caribbean, which she visited with the tall ship *Statsraad Lehmkuhl* in 2021. Throughout her Ph.D. journey, Johanne has developed both scientific expertise in ocean currents in the North Atlantic and developed her ability to communicate scientific findings to future generations in different countries and cultures.

Tore Mo-Bjørkelund is a Ph.D. candidate at NTNU, focusing on adaptive sampling strategies for autonomous underwater vehicles and exploring how multiple vehicles can be coordinated for measurements. In addition to his scientific work, Tore is one of the founders of Skarv Technologies AS, a technology provider specialized in developing and delivering sensing solutions tailored for underwater applications. Skarv Technologies offers sensors and robotic solutions to for example the aquaculture industry. In 2023, the Skarv Technologies was selected as one of only two Norwegian companies to be part of NATO's new accelerator program, DIANA. Through this program, Skarv Technologies has the opportunity to contribute to technological solutions needed for improved and more autonomous monitoring of strategic areas and infrastructure. Tore's career is a notable example of how a scientific background in technological development can serve as an excellent foundation for a successful business career.

Doreen Kohlbach completed her postdoctoral position with the Nansen Legacy partner NPI in May 2023. She continued to work for the Nansen Legacy until March 2024 to finalize a synthesis paper on physical, chemical and biological properties in the central Arctic Ocean. Doreen's main interest is to determine on what food sources different Arctic species depend. Her approach is centered around biochemical analyses of food sources, allowing her, for example, to determine the significance of sea-ice algae in zooplankton diet. Throughout her time with the Nansen Legacy, Doreen led and contributed to several publications in scientific journals, conference presentations, and outreach activities. Based on these qualifications, among others, Doreen was offered the opportunity to lead a Junior Research Group at the Alfred Wegener Institute in Germany.

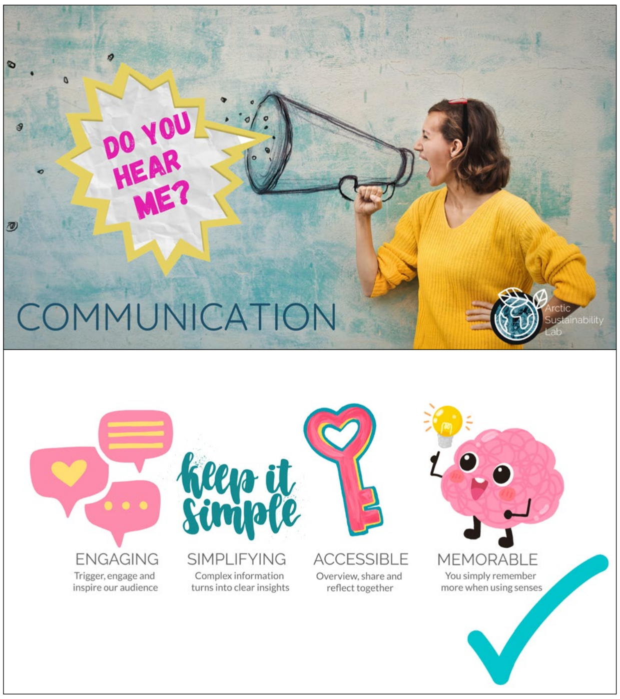
Photo: Kay Jørgensen

Early career scientists learn to communicate science to policymakers and the public

Researchers often get wrapped up in the details of their work and communicate with their peers using scientific jargon. To effectively share scientific results also with the general public and policymakers, requires good communication skills that tailor the information specifically to the audience. Early career scientist learned how to do this during a workshop preceding the symposium organized by the Nansen Legacy in November 2023.

Important scientific findings are useless when they are not communicated to the world. It is, therefore, essential that researchers know how to share their results and make them stick with the audience. An early career event prior to the symposium "Towards the new Arctic Ocean – past, present, future" addressed this need and invited early career scientists from the Nansen Legacy and outside the project to learn specific communication skills. During the workshop, participants were trained by two science communication experts. Fern Wickson, professor in ocean leadership, political scientist, and knowledge broker, started off by explaining how to effectively convey scientific results to policymakers. After Wickson's presentation, the participants paired up and worked with their peers on a 1-minute elevator pitch about their scientific work. The second expert was Ann Eileen Lennert, a community engagement specialist and narrative cartographer with a Ph.D. in environmental anthropology and sustainability science. She trained the early career researchers how to communicate their science to the general public, with a specific focus on making science engaging and understandable for a 12-year-old. Lennert's key advice to the researchers was to use a storytelling approach because this makes it easier for laymen to relate to scientific findings. The participants were again given the chance to practice this method with their peers before the afternoon was concluded with a presentation of the professional network *Association of Polar Early Career Scientists* (APECS).

Overall, this early career event was highly successful. It allowed the participants to learn new communication skills in a hands-on manner and prepared them to present their work to senior colleagues during the symposium. Moreover, the early career scientists could extend their professional network in an informal setting, which was especially appreciated by those who started their careers during the Covid-19 pandemic.



Do you hear me? Simple and powerful communication from Ann Eileen Lennert

"It was great to meet other early career scientist and to learn how to communicate your findings to non-scientists"

Christine Gawinski, UiT

Martí Amargant-Arumí at the Gordon Research Conference with his excellence award for poster presentation.
Photo: Marit Reigstad

Early career scientists at international conferences abroad

Now that the Nansen Legacy project is drawing closer to the end, most of the early career scientists are working hard to synthesize and publish their findings. International conferences provide an excellent platform to share and communicate the newest discoveries with the international science community and to build a professional network.

Several Nansen Legacy early career scientist and some of their supervisors at the ASLO conference.
Photo: Khuong van Dinh

ASLO Aquatic Sciences Meeting, Spain

With over 2500 participants, the ASLO Aquatic Sciences Meeting is a very large international conference. For many of the 10 Nansen Legacy early career attending the meeting, the days were highly inspiring, but, at times, also a bit overwhelming. In total, nine oral presentations and several poster presentations were given by Nansen Legacy early career and senior scientists. The contributions covered a range of different topics, including the effect of contaminants on arctic organisms, the seasonality of marine calcifying organisms, and new details on how the changing climate affects the Barents Sea ecosystems. Under the lead of Khuong van Dinh, a team of Nansen Legacy researchers also organized a session entitled *"Defining drivers and impact of climatic change and other anthropogenetic stressors on polar ecosystems: for long-term assessment of resilience, functionality and services"*. The session was well received by the international colleagues, and scientists from 12 different countries contributed with 18 oral presentations and 5 posters. The ALSO conference provided both early career and senior scientists in the Nansen Legacy project the opportunity to share their work, engage in discussions on new findings and the research projects of the future, and to place the research of the Nansen Legacy into a global context. ■

Gordon Research Conference, USA

Early career scientists had a strong presence at the 2023 Gordon Research Conference for Polar Marine Science in Ventura, USA. This conference focuses on sharing and discussing yet unpublished findings and is attended by scientists working on pressing questions related to the Arctic and Antarctic marine system. Seven early career scientists from the Nansen Legacy project attended the meeting, representing various Arctic disciplines across five scientific institutions in Norway. Among them was Ph.D. candidate Martí Amargant Arumì, who presented details on how the presence and absence of sea ice in the Barents Sea impact the smallest plankton and bacteria. For his highly informative poster, he received the "Excellence award for poster presentation". Associated with the Gordon Conference, also the one-day Gordon Research Seminar for early career scientists was arranged. Nansen Legacy members Zoé Koenig, Cheshtaa Chitkara, and Christine Gawinski presented their work during the seminar and integrated their newest findings from the Barents Sea into the knowledge framework of polar marine science. All Nansen Legacy early careers had a successful and educational conference, with excellent opportunities to network across polar regions, disciplines, and career stages.

"I presented my work, managed to catch many interesting talks, and made contacts with researchers that I would not have met otherwise."

Snorre Flo, UNIS

Ph.D. theses 2023

In 2023, seven doctoral students successfully defended their degrees. Their research encompassed diverse topics, including but not limited to bottom-dwelling organisms, risk assessment of autonomous marine systems, and satellite data. The breadth of their work reflects the diverse range of topics addressed within the Nansen Legacy project. Congratulations to all the recently graduated doctors!

Èric Jordà Molina was an affiliated Ph.D. student in the Nansen Legacy project and he graduated from Nord University (supervisors: H. Reiss, Nord, A. Sen, UNIS, P. Renaud, APN/ UNIS, B. Bluhm, UiT, M. Silberberger, IOPAN). Èric's work revealed that the abundance and community composition of large bottom-dwelling organisms (> 0.5 mm) in the northern Barents Sea changed minimally with season. However, the composition bottom-dwelling species underwent significant changes between 2003 and 2017 due to a more frequent inflow of warm Atlantic water into the area. The study also suggests that the remineralization rates of the bottom-dwelling organisms will likely increase if the northern Barents Sea warms, as predicted by model simulations.

Reference: Èric Jordà Molina (2023) Spatio-temporal dynamics of soft-bottom macrobenthic communities in a rapidly changing Arctic: a case study of the Northwestern Barents Sea. Ph.D. thesis, NORD University

Griselda Anglada-Ortiz successfully defended her dissertation at UiT The Arctic University of Norway (supervisors: T.L. Rasmussen, UiT, M. Chierici, IMR, A. Fransson, NPI, K. Zamelczyk, UiT, P. Ziveri, UAB Autonomous University of Barcelona). Griselda studied the impact of ocean acidification on two groups of planktonic organisms with calcareous shells. Her research shows that both pteropods and foraminifers were present in the Barents Sea throughout the year, although their abundances varied with the seasons. It was also concluded that pteropods are likely more affected by the ongoing ocean acidification. As pteropods contribute more to the flux of inorganic and organic carbon from the water to the sediment than foraminifers, this may affect the carbon dynamics in the future Arctic Ocean. The shells of foraminifers found in the sediment of the northern Barents Sea further suggested dissolution processes, and this may limit their potential to use them to reconstruct the past.

Reference: Griselda Anglada-Ortiz (2023) Planktonic foraminifers and shelled pteropods in the Barents Sea: Seasonal distribution and contribution to the carbon pump of the living fauna, and foraminiferal development during the last three millennia. Ph.D. thesis, UiT The Arctic University of Norway

Ina Nilsen graduated from UiB (supervisors: C. Hansen, IMR, A. Olsen UiB, Ø. Langangen, UiO, I. Kaplan, NOAA Fisheries, USA). Her dissertation focuses on understanding the uncertainty that is associated with model simulations of ecosystems. Ina's work demonstrates how the use of multiple ecosystem models of varying complexity can help quantify this uncertainty and provide valuable insights for fishery management. Her research also investigates the effects of future climate changes on marine species, and how uncertainty related to future projections can arise due to differences in the resolution of the physical forcing and how the species thermal tolerance and species interactions are represented in the models.

Reference: Ina Nilsen (2023) Dealing with uncertainty in ecosystem models along three axes; resolution, forcing and projections. Ph.D. thesis, University of Bergen

Ivan Cautain was a Ph.D. student affiliated with the Nansen Legacy and he graduated from University of the Highlands and Islands in the United Kingdom (supervisors: B.E. Narayanaswamy, Scottish Association for Marine Science, UK, K.S. Last, Scottish Association for Marine Science, UK, B.A. Bluhm, UiT, P.E. Renaud, UNIS, D. McKee, University of Strathclyde, UK). Ivan utilized lipid biomarkers to assess the relative importance of sea ice-derived, water column-derived, and terrestrial-derived organic matter for bottom-dwelling organisms. His findings indicate that sea ice-derived organic matter can play a significant role as food for bottom-dwelling organisms in certain regions and seasons. Additionally, his study revealed that it is not always the same drivers triggering the food input to the sea floor in different Arctic shelf seas.

Reference: Ivan J. Cautain (2023) Investigating the importance of different sources of organic matter as food for the benthos on three Arctic shelves, Ph.D. thesis, University of the Highlands and Islands, UK

Muhammad Asim successfully defended his dissertation at UiT The Arctic University of Norway (supervisors: K. Blix, UiT, A. Matsuoka, University of New Hampshire, USA, C. Brekke, UiT, M. Reigstad, UiT, T. Eltoft, UiT). Machine learning-based algorithms are becoming increasingly common for estimating concentrations of water quality indicators such as chlorophyll a or colored dissolved organic matter from remotely sensed satellite images. To provide high-quality input data to the machine learning models, the satellite-acquired images need to be corrected for atmospheric effects, such as for example the scattering of light from neighboring sea ice into the sensors' field of view. In his work, Muhammad evaluated the performance of state-of-the-art algorithms correcting atmospheric effects and developed improved machine leaning-based methods to accurately retrieve concentrations of water quality indicators from high resolution satellite-derived data.

Reference: Muhammad Asim (2023) Optical remote sensing of water quality parameters retrieval in the Barents Sea. Ph.D. thesis, UiT The Arctic University of Norway

Ruochen Yang graduated from NTNU (supervisors: I. Bouwer Utne, M. Ludvigsen, I. Schjølberg, all NTNU). In his dissertation, he focused on analysing and controlling the safety in operations of autonomous marine systems. Autonomous marine systems have evolved over the past years. They are already used for unmanned and autonomous ocean monitoring and will likely play an important role in future ship traffic. Ruochen both reviewed existing methods and models assessing the operation safety and identified the main research challenges and gaps. He investigated which hazards or hazardous events may affect the safe and reliable operations of autonomous marine systems and how they could do so. He particularly delved into the safe operation of under-ice autonomous underwater vehicles.

Reference: Ruochen Yang (2023) Methods and models for analyzing and controlling the safety in operations of autonomous marine systems. Ph.D. thesis, Norwegian University of Science and Technology

Stephen G. Kohler defended his Ph.D. dissertation at NTNU (supervisor: M. Van Ardelan, NTNU, K. Ndungu, NIVA, L.-E. Heimbürger-Boavida, Institut Méditerranéen d'Océanologie, France). Stephen investigated the seasonal variation of total mercury and the toxic methylated mercury concentrations in the northern Barents Sea. He found that the total mercury concentration in this region was approximately 33% lower in winter than in summer. In contrast, the concentration of methylated mercury was lowest in spring and higher in autumn and winter. Stephen's work highlights the temporal variation of mercury concentrations in the Arctic Ocean in the northern Barents Sea, with potential seasonal implications for mercury bioaccumulation in the Arctic marine food web.

Reference: Stephen G. Kohler (2023) Seasonal biogeochemical cycling of mercury on the Arctic Ocean shelf. Ph.D. thesis, Norwegian University of Science and Technology

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Master's theses 2023

Twelve master's students defended their degrees. Congratulations to all of them for their successful work!

Amalie Marie Bårnås Gravelle successfully defended her thesis at UiO (Supervisors: K. Borgå, UiO, K. Van Dinh, UiO, J.E. Søreide, UNIS). Amalie Marie conducted experiments in which she tested the potential interactive effects of pyrene, a toxic component of crude oil, elevated temperature, and ocean acidification on the important Arctic zooplankton species *Calanus glacialis*. She found that the cumulative effect of these stressors reduces the survival and activity of *Calanus glacialis*, and potentially progresses to the next generation, as indicated by lowered hatching success of eggs.

Reference: Amalie Marie Bårnås Gravelle (2023) How will oil pollution and climate change affect an Arctic key zooplankton? The interactive effects of pyrene, elevated temperature, and ocean acidification on fitness-related traits in *Calanus glacialis*. Master's thesis, University of Oslo

Andreas Lunde graduated from the University of Helsinki, Finland (supervisors: J. Vanhatalo, University of Helsinki, J.E. Søreide, UNIS). Andreas investigated the species composition of large zooplankton (> 10 mm) in 11 fjords around Svalbard in autumn. Most species were found everywhere, but species abundances and body sizes differed between fjords dominated by Arctic-derived versus Atlantic-derived waters. Overall, krill and the Atlantic amphipod *Themisto abyssorum* were most numerous, while the large Arctic amphipod *Themisto libellula* was rarely found.

Reference: Andreas Lunde (2023) Distribution, abundance and length of macrozooplankton species in Svalbard fjords. Master's thesis, University of Helsinki, Finland

Angelo Ciambelli finished his master's thesis at UiT The Arctic University of Norway (supervisors: C. Svensen, UiT, A. Wold, NPI, S. Majaneva, NTNU). Angelo's study was one of the first investigating the seasonal diversity and distribution patterns of gelatinous plankton in different water masses of the northern Barents Sea. *Fritillaria borealis*, *Oikopleura* sp. and *Aeginopsis laurentii* were identified as predominant taxa and it was shown that the seasonal dynamics and species composition differed in the Atlantic and Polar Waters.

Reference: Angelo Ciambelli (2023) Gelatinous zooplankton diversity, distribution and seasonality in the northern Barents Sea. Master's thesis, UiT The Arctic University of Norway

Anne Mol conducted her thesis at UNIS and defended it at the University of Amsterdam, The Netherlands (supervisors: S. Flo, A. Vader, both UNIS). Anne investigated the diversity, prevalence, and spatiotemporal variation of parasites infecting the small copepods *Oithona similis*, *Microcalanus* spp., and *Microsetella norvegica* by DNA metabarcoding. She found that the community composition and the infection rate of parasites in these copepods changed seasonally.

Reference: Anne Mol (2023) Characterization of eukaryotic parasites in three small copepods. Master's thesis, University of Amsterdam, The Netherlands

Eli Ruud Dankel finished her thesis at UiO (supervisors: L. Šupraha, UiO/ NIVA, B. Edvardsen, UiO, W. Eikrem, UiO/ NIVA, K. Saubrekka, UiO). She investigated in her work the seasonality of the phytoplankton group coccolithophores in the Barents Sea using scanning electron microscopy and metabarcoding. Both methods indicated that the more species were present at stations that were influenced by the North Atlantic current.

Reference: Eli Ruud Dankel (2023) Arktiske kalkflagellater: et morfologisk og molekylært dypdykk i det nordlige Barentshavet. Master's thesis, University of Oslo

Jildou Minke Dijkstra finished her master's thesis at UNIS and graduated from the University of Amsterdam, The Netherlands (supervisors J.E. Søreide, UNIS, K. Peijenenburg, University of Amsterdam). Jildou studied the combined effect of Ocean acidification and ocean warming on the key Arctic zooplankton *Calanus glacialis.* She found that pH and temperature had a synergistic effect and led to increased DNA damage and mortality. Increased seawater temperatures increased the metabolic activity and enhanced lipid depletion and earlier molt, leading to increased mortality.

Reference: Jildou Minke Dijkstra (2023) Effects of ocean warming and acidification on overwintering Arctic zooplankton. Master's thesis, University of Amsterdam, The Netherlands

Hanna Myhre Walbækken completed her thesis at UiO (supervisors: W. Eikrem, UiO/NIVA, B. Edvardsen, UiO, K. Saubrekka, UiO, A. Hofgaard, UiO). She investigated the abundance and diversity of dinoflagellates in the Barents Sea during a low and a high sea ice situation in August 2018 and August 2019. Hanna found that DNA metabarcoding, light microscopy and scanning electron microscopy have a different potential to identify dinoflagellates, and that different dinoflagellate genera were present during the contrasting sea ice situations.

Reference: Hanna Myhre Walbækken (2023) Dinoflagellate diversity in the Barents Sea: a comparative identification analysis. Master's thesis, University of Oslo

Khrystyna Gryn successfully defended her thesis at UiO (supervisors: B. Edvardsen, UiO, L. Šupraha, UiO/NIVA, W. Eikrem, UiO/NIVA, K. Saubrekka, UiO). Khrystyna's work focused on water samples collected along a south-north transect in the Barents Sea in August 2019. She used DNA sequencing, phylogenetic analyses, and morphology to identify common groups of phytoplankton and sea ice algae and revealed that typically (endemic) Arctic algae dominated. Algae with a cosmopolitan or polar distribution were only rarely observed.

Reference: Khrystyna Gryn (2023) Biodiversity and distribution of Arctic phytoplankton and ice algae. Master's thesis, University of Oslo

Nathalie Calvet graduated from UiT The Arctic University of Norway (supervisors: A. Altenburger, B. Bluhm, both UiT). She utilized data from the Global Biodiversity Information Facility (GBIF) on the distribution of marine invertebrates in the Barents Sea. Based on these data, Nathalie investigated potential changes in abundance and distribution of these organisms over the past 100 years. She found a drastic change in the species composition in the southern and central Barents Sea after 1980, and a more gradual change seemed to take in the distribution of species after 2000 in the entire Barents Sea.

Nathalie Calvet (2023) Changes in the distribution of marine invertebrates in a warming Barents Sea over the last century. Master's thesis, UiT The Arctic University of Norway

Silje Mortensen completed her thesis at UiT The Arctic University of Norway (supervisor: T. Pedersen, UiT). She used the ecosystem model Ecopath with Ecosim to investigate how warmer waters, which will likely occur in the future Barents Sea, affect fish species of economic value when no, moderate, and intense future krill fisheries would take place. Her study revealed that intense krill fisheries would result in serious negative consequences on the catch of commercially used fish species.

Reference: Silje Mortensen (2023) Effekter av økt temperatur og et framtidig krillfiske på fangstutbytte i Barentshavet - en økosystemmodellering i Ecopath med Ecosim. Master's thesis, UiT The Arctic University of Norway

Tassawer Hussain completed his degree at UiT The Arctic University of Norway (supervisors: M. Reigstad, Y.V. Bodur, G. Anglada-Ortiz), in which he studied the sinking of particulate matter in the northern Barents Sea during different seasons. Tassawer's work revealed that a lot of resuspended inorganic matter can sink out during the polar night, while fresh organic matter sinks during summer. This thesis highlights the influence of environmental conditions and seasons on the downward flux of calcium carbon and particulate matter in the Barents Sea.

Reference: Hussain T (2023) Seasonal variations in vertical flux of particulate matter and composition in the northern Barents Sea. Master's thesis, UiT The Arctic University of Norway

Truls Pedersen defended his master's thesis at UiT The Arctic University of Norway (Supervisor: T. Pedersen, UiT). He investigated how the two commercially important fish species Atlantic cod and haddock respond to the future rising water temperature in the Barents Sea. Truls used the ecosystem model Ecopath with Ecosim and found that haddock seemed to benefit more from the higher temperatures than cod. Also, the biomass of other commercially used boreal fish species rose under higher temperature settings, while the biomass of Arctic fish species declined.

Reference: Truls Pedersen (2023) Effekter av framtidige endringer i temperatur og fiskedødelighet på torsk (*Gadus morhua*) og hyse (*Melanogrammus aeglefinus*) i Barentshavet - en økosystemmodellering med Ecopath og Ecosim. Master's thesis, UiT The Arctic University of Norway

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SEAONICS
KRONPRINS HAAKON

Photo: Robin Hjertenes

Photos: Thomas B. Eckhoff

Outreach

In 2023 Nansen Legacy scientist shared the recently obtained new understanding of the Barents Sea and adjected Arctic Ocean widely. The knowledge was communicated to anyone interested, from 5-year-old kindergarten children to His Majesty King Harald V.

Photo: Lena Seuthe, UiT

For and with kids

As part of the Arctic Frontiers "Science for kids" project, Lena Seuthe, former project administrator in the Nansen Legacy, took 80 5-year-olds, from six different kindergartens, on an imaginary research expedition to the North Pole. During this journey, the children collected samples from the seafloor at different locations between Tromsø and the central Arctic Ocean and learned which animals dominated in the different areas. Lena Seuthe also gave a lecture on "research in the Arctic" to high school students from the south of France, using the Nansen Legacy project as an example. The students experienced how geologist take samples on board research vessel *Kronprins Haakon* using Virtual Reality glasses. Project leader, Marit Reigstad, held a lecture for high school students from Finland. She talked about Arctic development and how the marine climate and ecosystem are in rapid change.

For and with the king

Marit Reigstad was invited to give the 2023 Nansen Memorial Lecture, an annual event organized by the Norwegian Academy for Science and Letters (Det Norske Videnskaps-Akademi). In her lecture, entitled "*Fra Fram til FF Kronprins Haakon – Arven etter Nansen møter et ishav i endring*", Reigstad discussed how the Nansen Legacy project aims to obtain a better understanding on how climate change affects the Barents Sea. She explained the physical drivers behind the observed changes, the ecosystem's response, what traces human activities leave behind, and what the Barents Sea might look like in the year 2050. The event was attended by His Majesty King Harald V.

For and with Scientists

Nansen Legacy researchers presented in total more than 150 scientific talks and posters at 43 different conferences and workshops in 2023. More than 50 of these presentations were given at the Nansen Legacy symposium that was organized in November 2023 in Tromsø. Amongst the researchers presenting their findings at conferences were for example Guillaume

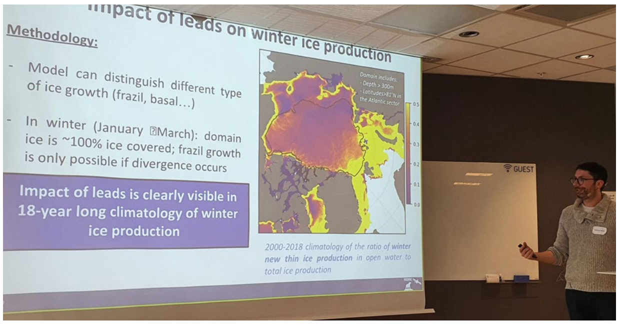


Photo: Signe Aaboe, MET

Boutin, Einar Olason, and Anton Korosov (all from NERSC). At six different conferences, they shared new insights on sea ice development and ice-ocean interactions based on model simulations. Sissel Jentoft (UiO) was an invited speaker at the European Marine Biology Symposium and the Society for Molecular Biology & Evolution where she talked about genomic variation and architecture in marine fish. Nansen Legacy was also host to sessions and several side events and panel debates at the Arctic Frontiers conference, the Svalbard Science Conference, and the ASLO conference. At these events, human impact on polar ecosystems, the future of polar science, how we go from observation to adaptation, and how we can bring together scientist and society were discussed.

Nansen Legacy in mass media

Nansen Legacy also shared their knowledge in different mass media. Among others, UNIS early career researchers Kjersti Kalhagen and Ane Cecilie Kvernvik were interviewed by the local newspaper *Svalbardposten*. While Kalhagen studies the Gulfstream, Kvernvik examines microscopic single-celled organisms in the ocean. In their interview, the two researchers explain how the Nansen Legacy stimulated them to collaborate. The Nansen Legacy was also mentioned in international media, among others, in the English Edition of the South Korean daily newspaper JoongAng Ilbo, and our post doc Amanda Ziegler was interviewed on effects of Arctic climate change in a documentary by PhoenixTV, Hong Kong. In addition to print media, the project's data manager, Luke Marsden (MET), made several YouTube videos where he informed and shared how to work with, and publish, datasets. ■

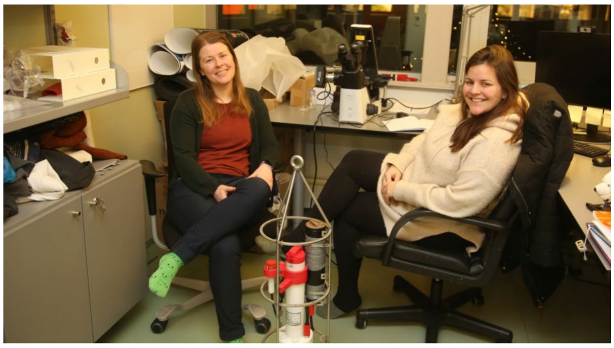


Photo: Ole Magnus Rapp, Svalbardposten.no


FLOATATION
BY REGATTA

Photo: Andreas Wolden

International collaboration and mobility

Collaboration stands as one of the pillars of the Nansen Legacy project, fostering partnerships not only among researchers at different Norwegian institutions but also on an international scale. Four stories of (inter)national research stays in 2023 are highlighted here.

Nansen Legacy in Seattle

In early summer 2023 researcher Cecilie Hansen, IMR, travelled from Bergen to the University of Washington, USA, to meet and work with researchers from the Northwest Fisheries Science Center (NOAA). Hansen studies, among others, fish ecology using the Atlantis framework model. This model is a tool that allows to predict how different fish species will respond to future climate change. Until recently, there were several limitations with this model, but the research group in Seattle has now developed solutions that significantly enhance its predictive outcomes. Hansen, along with other Atlantis users, learned about these improvements in the modelling code during her stay.

During the last weeks of Hansen's stay, a summer camp for Atlantis users was organized. Participants discussed with Elizabeth Fulton, the 'mother' of Atlantis, new ideas, challenges, bug-fixes, and code updates. Back in Bergen, Hansen is well equipped with a deeper understanding of the model and her future work with it. Her goal is to enhance our understanding of how future climate change may affect the future Barents Sea fish species.

"It was perfect that we could spend time discussing potential solutions."

Cecilie Hansen, IMR

Cecilie Hansen (left) in Seattle with other Atlantis users
Photo: Cecilie Hansen

Nansen Legacy in Denmark

In May 2023, Ph.D. candidate Tiziana Durazzano from UiT traveled to DTU Aqua (National Institute of Aquatic Resources at the Technical University of Denmark) to meet and work with her supervisor, Andre Visser. During her stay, Durazzano enhanced her proficiency in the functional traits approach and learned how to apply this method to Nansen Legacy datasets. Additionally, the early career scientist actively participated in discussions, exchanging ideas and perspectives with her colleagues at DTU Aqua. This experience provided her with fresh insights into her specific research objective, propelled her forward in her Ph.D. project, and concurrently allowed her to obtain a better understanding of this type of ecosystem analysis. A second research stay followed in autumn 2023, providing a more in-depth exploration of her data handling, and significantly advanced her Ph.D. project.

"My journey to Denmark was a multifaceted experience, I did not only meet my supervisor, but it also enabled me to establish connections with professionals at DTU Aqua and gain inspiration for the progression of my Ph.D. project."

Tiziana Durazzano, UiT

Tiziana Durazzano with her Ph.D. supervisor Andre Visser.
Photo: Tiziana Durazzano

Carolin Uhlir studying sea spiders at UiT.
Photo: Bodil Bluhm

Nansen Legacy hosting international researchers

The international collaboration within the Nansen Legacy was not only strengthened by project members traveling abroad but also by inviting and hosting researchers at Norwegian institutions. In December 2023, Carolin Uhlir from the Senckenberg Institute in Hamburg, Germany visited Bodil Bluhm and Andreas Altenberger at UiT The Arctic University of Norway. The goal of Uhlir's visit was to study the taxonomy of sea spiders from the Nansen Legacy cruises to the Barents Sea. Although more than 40 sea spider species live in the high north, their taxonomic identification is often only done on a coarse level. Uhlir's work focuses on improving the identification of the spider species and other marine species.

The Nansen Legacy mobility grant allowed Uhlir to get a head start in her Ph.D. project, supervised by Saskia Brix, Senckenberg Institute, and Bodil Bluhm, UiT. During the visit, she could build her network in Norway. In return, the organisms identified by Uhlir have now been incorporated into the collection of the Tromsø University Museum, a part of UiT, representing a small but significant contribution to the legacy of the Nansen Legacy project.

"Thanks to my visit I was able to lay an important foundation for my Ph.D. thesis. Working with the scientists and staff in Tromsø opened up opportunities for new collaborations."

Carolin Uhlir, Senckenberg Institute, Hamburg, Germany

Yasemin Bodur and Maria Digernes during their writing retreat.
Photo: Yasemin Bodur

Mobility within Norway

The Nansen Legacy also supported mobility within Norway. Yasemin Bodur, a Ph.D. candidate at UiT, visited Maria Digernes, a Ph.D. candidate at NTNU, in January and October 2023 to work on a joint scientific publication. Bodur, a marine ecologist, and Digernes, a marine chemist, cooperate on investigating the aggregation processes of dissolved organic matter. Coming from different scientific disciplines, Bodur and Digernes realized that both definitions and terms were used in different ways in their respective fields. Bodur`s research stays allowed the two researchers to establish a common understanding of their new findings and to compile the implications of the aggregation processes in the ocean for both marine chemistry and ecology. Their joint work will be submitted to a scientific journal soon. ■

"The in-person meetings really set the baseline for understanding each other's perspective and having a clear idea of a scientific publication".

Yasemin Bodur, UiT

"Writing can generally be quite isolating but through the writing retreat we were able to motivate each other through scientific discussions!"

Maria Digernes, NTNU

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.

International colleague Mariko Hatta at the Arctic Science Summit Week side event.
Photo: Arctic Passion

Contributions to Norwegian marine management

The Nansen Legacy facilitates integration of project-based results both through our researcher's contribution to assessment reports, as well as through dialog with the Advisory Group for monitoring. The Nansen Legacy was invited to present an overview of new knowledge from the project that is relevant to Norwegian marine management at two meetings with the Advisory Group for Monitoring in 2023. The group is part of the ecosystem-based management of Norwegian marine regions and responsible for Annual status reports, Assessment reports and updated marine status and environmental conditions every fourth year. More than 50% of the 31 scientists authoring the "Panel-based Assessment of Ecosystem Conditions of Norwegian Barents Sea Shelf ecosystems" (Siwertsson et al. 2023), are Nansen Legacy researchers. The two presentations given to the Advisory Group for Monitoring meetings in May and November, focused on an overview of results, societal relevance and how to best implement new knowledge from the project, while in November more specific contributions to indicators relevant for the Arctic Norwegian sector of the Barents Sea were identified. The Nansen Legacy contributes complementary knowledge to the management institutions with better coverage on seasonal resolution on themes including environmental characteristics, lower trophic levels, sea ice characteristics and biology, contaminants, food web and production studies, and biodiversity. Member of the The Advisory Group for Monitoring and lead of the Impact and Legacy work package in Nansen Legacy Kai H. Christensen gave the presentation in May while project leader Marit Reigstad presented in November.

Effects of Climate Change on the World´s Ocean (ECCOW5)

The ECCOW5 conference in Bergen, April 2023, was organized by international organizations working to provide and translate knowledge to sustainable use and healthy oceans (ICES, PICES, UNESCO, FAO and the Institute of Marine Research). Several Nansen Legacy researchers were invited or given opportunities to present results related to the project. Katrine Borgå, Randi Ingvaldsen, Joel Durant, Nicholas Dupont, Elizabeth Jones and Elliot Sivel presented research on the Barents Sea and adjacent marine systems on themes including cumulative anthropogenic impacts; Atlantification and borealization; non-linearity in interactions between fish stocks; survival of polar cod with increased borealization; ocean acidification; combined effect of fisheries and climate change on the ecosystem. This research increases our understanding of the multiple impacts and changes the Arctic oceans experience, and the responses in the ecosystem. It is therefore important to include updated knowledge on these topics in management and use of the oceans.

Arctic Science Summit Week 2023

The side event "*How to improve models, observations, and collaborative approaches to understand the future biogeochemistry in the Arctic Seas*" was organized as a joint effort between the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and the Nansen Legacy. The Nansen Early career scientist Filippa Frasner gave one of the keynote presentations on multiyear predictability capacity on phytoplankton in the Barents Sea. Another Nansen Legacy early career scientist, Elisabeth Jones, presented results from seasonal investigation on the Barents Sea ocean acidification status. Our Japanese colleagues Yuanxin Zhang and Mariko Hatta contributed with comparative aspects on the Pacific Arctic sector.

Side events and panel discussions

The Nansen Legacy organized and participated in several side events and panel discussions in 2023, some are presented in more detail elsewhere in this annual report. Including topics are: sea ice and shipping at the Arctic Frontiers conference, contributions to Synoptic Arctic Survey events with an international collegium to harmonize and collect data on a Pan-Arctic scale, a side event on drivers and human impacts on polar ecosystems during the ASLO conference, and contributions to the Atlantic Arctic Distributed Biological Observatory, with EU project Arctic Passion, to coordinate existing time series to larger observational systems. During the Arendal week, we shared experiences and values of large collaborating efforts like the Nansen Legacy with the organizers of the Future Arctic Ocean project. During the symposium in November, we discussed how to translate research into useful knowledge for society with management and relevant stakeholders. ■

References

Siwertsson A., B. Husson, P. Arneberg et al. (2023). Panel-based Assessment of Ecosystem Condition of Norwegian Barents Sea Shelf Ecosystems. ***Rapport fra havforskningen 2023-14.*** ISSN: *1893-4536*.

Photo: Frida Cnossen

Photo: Audun Rikardsen, UiT

Concentration of human-made contaminants in minke whales

Do you know the common denominator of the insecticide DDT, a Teflon frying pan, and some electric cords? All of these items contain and may release human-made contaminants and several of them have been found in 17 minke whales in the Barents Sea. The contaminant levels in the whales were too low to cause negative health effects for the whales, but monitoring contaminant levels in the commercially used minke whale is also crucial for human health.

Whales as sentinel species

The Arctic is often considered to be remote and pristine, but it is well-connected to the rest of the globe through ocean currents and atmospheric circulation. Various human-made contaminants can therefore reach the Arctic, including persistent organic pollutants used in agricultural insecticides, flame retardants used in electronics, and fluorinated synthetic compounds making frying pans 'non-stick', rain jackets water repellent, and waxed skis glide. Released to the environment, these contaminants can be taken up by organisms, and particularly high contaminant concentrations are found in long-lived predators, such as whales or polar bears. When top predators are commercially hunted, like minke whales in Norway, it is crucial to monitor their contaminant levels to avoid negative effects on human health.

Contaminant levels in adult minke whales

Clare Andvik and colleagues recently measured a range of contaminants in adult minke whales in the Barents Sea. Through cooperation with a commercial whale hunter, additional capture was avoided. The concentrations of persistent organic pollutants and mercury in the whales' muscles, liver, and blubber were lower or similar to those reported 20 years ago. This suggests that the strict regulation of these contaminants has at least resulted in a stabilization of the contaminant levels. It is however assumed that leaching of these contaminants from thawing permafrost may affect coastal marine organisms also in the future. In addition to the long-regulated contaminants, several recently introduced contaminants were also found in minke whales in the Barents Sea. Overall, the contaminant concentrations were below established thresholds both for whale health and for human consumption, and thus no direct negative health effects for the whales or humans are assumed.

Contaminant transfer from mother to unborn offspring

The study also showed that female minke whales can transfer contaminants to their offspring during pregnancy. The concentration of synthetic contaminants with fluorine atoms and several metals (e.g., lead, nickel) was higher in the unborn offspring compared to the mother. This suggests that the placenta, a temporary organ in the mother's womb regulating the supply of oxygen and nutrients, does not act as a barrier to certain metals and human-made contaminants. Thus, the unborn offspring of minke whales seems to be exposed to contaminants in the mother's womb, and it is currently unknown how this affects the minke whale population. ■

> "Female marine mammals are known to transfer contaminants to their offspring through both the placenta and the lipid-rich milk."

Clare Andvik, UiO

Reference:
Andvik C, **Haug T**, Lyche JL, **Borgå K** (2023) Emerging and legacy contaminants in common minke whale from the Barents Sea. *Environmental Pollution,* 319, 121001.

Photo: Christine Gawinski

Work with the user groups

When sea ice concentrations in the Arctic decrease, new shipping routes can emerge. New shipping routes mean new possibilities for the fishing fleet, cargo transport and tourist vessels. But increased ship traffic in the Arctic comes with risks. These shipping routes are under-explored and in remote areas where people and vessels are exposed to harsh conditions. Nansen Legacy researchers and user group members discussed possibilities and risks during a side event of the Arctic Frontier conference.

During the annual Arctic Frontiers conferences in Tromsø, the Nansen Legacy organized the side event *Changing Sea ice conditions in the northern Barents Sea – implications for activities.* The event connected scientists with user groups and policy makers to discuss how changing sea ice conditions can impact human activities in the Barents Sea.

A panel of six specialists shared insights on sea ice dynamics and ship traffic in (seasonally) ice-covered waters. The first presenter was Morten Mejlænder-Larsen, Director for Arctic Operation and Technology at Det Norske Veritas (DNV), an organisation that provides advice to the maritime industry. Larsen focused on existing knowledge gaps and what information is needed to successfully carry out planned activities in the Barents Sea. Øyvind Rinaldo, member of the Nansen Legacy reference group and senior advisor in the Norwegian Coastal Administration (NCA), followed. The NCA is a governmental agency that is responsible for water transport infrastructure along the Norwegian coast. Rinaldo explained how the NCA performs risk assessments, how research is used in these risk assessments, and what knowledge gaps scientist should focus on. The next three presenters were early career scientist Elina Efstahiou and researchers Angelika Renner and Øyvind Lundesgaard. They presented new knowledge and methods on sea ice conditions and the ability to observe sea ice and its dynamics. Senior scientist Malin Johansson ended the first part of the event with a presentation on how new satellite-based information can help detect oil spills near ice covered waters in case of an accident.

The panel debate during the Arctic Frontiers side event.
Photo: Trude Borch, Akvaplan-niva

In the second part of the event, Nansen Legacy board member Lars-Anders Breivik moderated a panel discussion between the six specialists and the audience. In a fruitful discussion the potential use of already existing knowledge on sea ice spatial distribution, the potential of sea ice buoys, and the possibilities to acquire new knowledge that is beneficial for the end-user, such as the fishing fleet, cruise ships, or cargo vessels were discussed. The debate showed how a tight communication between scientists and end users would help to better assess and mitigate risks of ship traffic in seasonally ice-covered waters of the northern Barents Sea and the adjacent Arctic Ocean.

The side event was organised by Paul Renaud, Marit Reigstad, and Trude Borch. ■

Illustrating science: Capturing complexity and emotion through artistic expression

The communication of scientific results is a challenging but increasingly important task. With science illustrator Frida Cnossen, the Nansen Legacy project hit the jackpot. Through her understanding and transformations, the Nansen Legacy fact sheets became a success, and complex results can be understood by users.

Frida Cnossen with her artwork at an exhibition in the MAMAC, Nice (France)
Photo: Frida Cnossen

How did you end up in the Nansen Legacy where you can combine both art and science?
I followed the science track in my education, as I have always been driven by curiosity and wanting to learn new things. Drawing and painting have been a lifelong passions and is for me the way to express myself. I was always drawing, painting, and crafting things as a child, and got fascinated by hyperrealism. For the most part I have taught myself how to draw, and I currently mainly work with soft pastels and oil painting. When I discovered some years ago that being a science illustrator is a profession, I realised that this was exactly what I wanted to do. It was a combination of luck, a coincidence, and a synchronicity of circumstances that I ended up doing this in the Nansen Legacy project. Paul Renaud, who was my master's thesis supervisor, helped me to get this position. When he told me the news, my eyes lit up with excitement and a slight sense of fear, as this was new to me but also an opportunity I had been dreaming of. I remember his words "you can just learn by doing it."

How does your science background help you make drawings and communicate?
I have a little bit of experience from working on the cellular level to an ecological scale, from working with gene modifications to cutting open fish stomachs. I also moved quite a bit, from the Netherlands where I was born to doing a biomedical science bachelor in the United States, to a Master in marine science in the warm and sunny south of France, and finally to a place where I can wear shorts only three times per year. Perhaps having been exposed to a diversity of fields helps me to communicate across various disciplines and visualize complex scientific information.

> "Having a clear key message is the key to a good science illustration."

What do you focus on to make the scientific message understandable?
Having a clear key message is the key to a good science illustration, and this should be the first thing the viewer picks up. This can be a challenge in complex scientific topics when there are lots of details that go along with the overall understanding. However, everything has a core that can be communicated, and from there it can be made as detailed as necessary. It is always a fun moment when the researcher and I hit a "lightbulb moment" and get a vision of what needs to be drawn.

What is your working process and how do you collaborate with the scientists?
It's quite funny how I currently have a unique collection of everyone's sketches and drawing skills. Some people know exactly what they want and what the illustration

"Octopus with the pearl"
Soft-pastel, 30x30 cm

should look like, then I get the request to "prettify" their drawing. Others come with a big excel sheet and tell me "Now draw something." While the last one is the most challenging, it is also the most fun, as I need to learn and understand the topic to come up with a clear visual representation.

Where do you get your inspiration from?

I am always in awe when I see a work from my favourite artist Marco Grassi or the detailed illustrations of marine organisms from Ernst Haeckel. It is fascinating to me how science illustrations have been important in documenting scientific information and discoveries for centuries, and still hold an educational value as of today. A discipline that started with detailed anatomical drawings has expanded itself to storytelling infographics that include narrative elements and contextualize scientific concepts.

"A mermaid's dream"
Soft-pastel, 30x40 cm

"Self-portrait"
Soft-pastel, 30x40 cm

What are your goals, and is there any specific direction in which you hope to specialize?

Without living anywhere near the Arctic before I came here, seeing photos, videos, and documentaries made me have a strong fascination towards this area, and I hope to contribute in a similar way. The scientific field has grown to be a lot more multidisciplinary and connected, which is needed to solve some of the world's biggest problems. The large amount of information that is available nowadays must also educate new generations. I hope to continue contributing with my illustrations in a way that makes scientific information more understandable, accessible, spark curiosity and interest, and engage people from all over the world. I hope to raise awareness that the Arctic is under threat through also an educational message, and that my art creates a deeper appreciation within people for the Arctic. I would also like to develop more animations and combine my hyperrealism with science. One example was an art piece I once made about the diet of polar cod, showing the development from what it eats when it's young to what it could eat when it becomes an adult. ■

art_frida

"The diet of polar cod"
Soft-pastel, 30x40 cm

Photo: Kay Jørgensen

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 in 2023, including results on fish numbers in the central Arctic Basin, recommendations on the effects of multiple stressors on organisms during winter, and news from data publishing.

Few fish in the deep Arctic Basin

As part of the International Agreement to Prevent Unregulated Fishing in the High Seas of the Central Arctic Ocean, Norway and the other signing states have the duty to contribute to an increased understanding of the central Arctic Ocean ecosystem and potential fish resources. The Nansen Legacy Arctic Basin cruise in September 2021 was able to sample the mesopelagic layer (200-1000 m depth) with a trawl in between the sea ice floes. Previously, only acoustic measurements have been conducted and they suggested an increased biomass. The trawling revealed very low fish abundances with a total of 7 fish individuals caught in 12 trawl hauls. In addition, large numbers of jellyfish and larger zooplankton were found, and they often belonged to sub-Arctic species. On the Yermak Plateau and the slope north of Svalbard, demersal trawling between the years 2012 and 2020 revealed in contrast that fish communities were dominated by Atlantic cod (in term of weight) and polar cod (in terms of numbers). Moreover, this region appeared to be a transition zone from more boreal species in the west to more Arctic species in the east. This shows that both the abundance of fish and its community considerably differ between the central Arctic basins and the shallower regions at the basins' edge.

Still knowledge gaps on the impact of multiple stressors during winter

Studies on the effect of multiple stressors in the Arctic marine ecosystems are often biased towards the summer season, when it is easier to access the Arctic. Our knowledge on how stressors impact the organisms and ecosystem during different seasons are therefore very limited. A new Nansen Legacy study points out why it is so important that studies of multiple stressors are conducted during all seasons. Factors like temperature, sea ice, darkness, and/or the phase of organisms' life cycle during winter can changes the magnitude of stressors, the effect of stressors, and the interaction between different stressors. Incorporating the effect of multiple anthropogenic stressors on organisms during winter is thus crucially important to assemble better ecological risk assessments, management plans, and conservation efforts.

Crude oil impact spawning time in polar cod

While it is well known that early life stages of polar cod are sensitive to crude oil exposure, less has been known about the effect of crude oil on adults. Nansen Legacy researchers carried out an experiment with wild caught polar cod, where adults were exposed to crude oil during their spawning period. The crude oil exposure resulted in earlier spawning compared to the control group, indicating the spawning period may be impacted by exposure. The eggs from exposed females had also a higher polycyclic aromatic hydrocarbon burden. A combined test of the effect of good or poor food availability with the crude oil exposure seemed not to have an effect. The effect of exposure on the adult gamete quality and impact on the next generation remains to be investigated.

Improved methods to understand sea ice dynamics

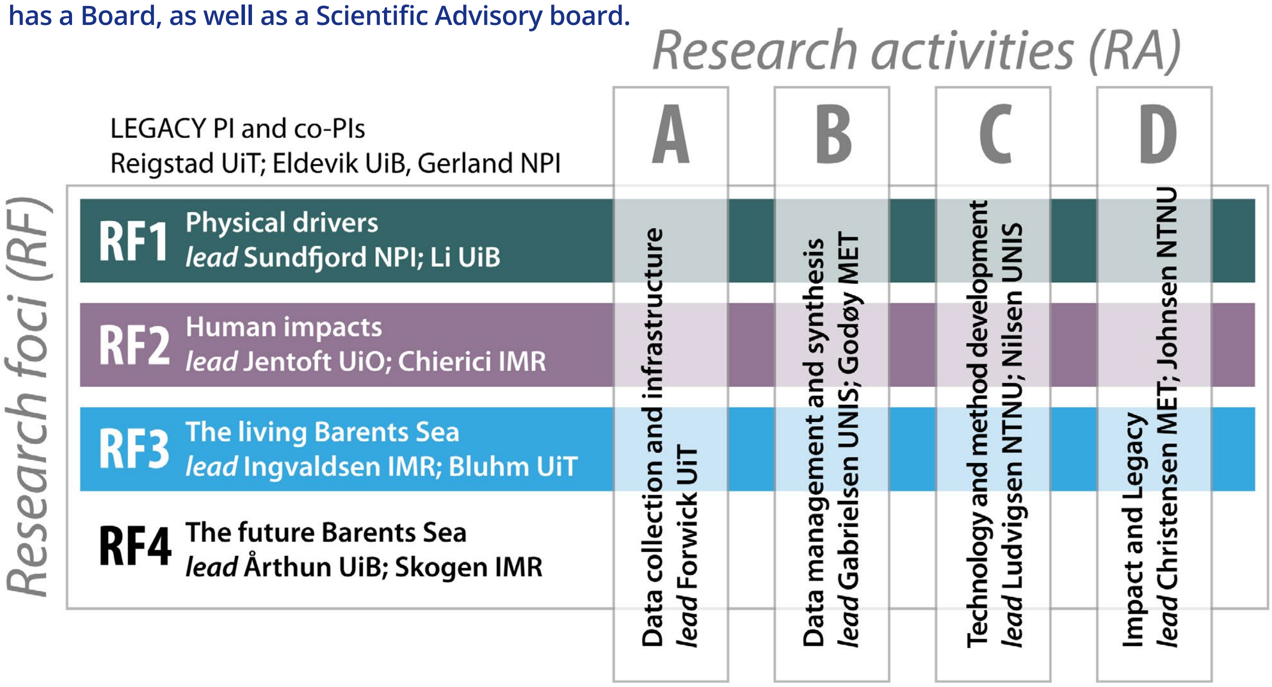
A new way of simulating sea ice in ocean-sea ice coupled models (brittle rheology) allows to reproduce sea ice deformations like fragmentation and collisions. Thus, this new method is able to provide a much more realistic representation of the sea ice dynamics including leads and ridges in the Arctic Ocean. Most of the Arctic sea ice is drift ice, and with increasingly thinner and more fragmented sea ice, more realistic sea ice models are needed that includes the dynamic sea ice. Nansen Legacy researchers investigated the role of leads and polynyas (open water between the ice floes) in the new model and found that up to 25-30% of the new sea ice formation between January and March took place in open leads. The improved ability to model sea-ice deformation can also improve the accuracy in short term sea-ice forecasts, although this is still in a test phase. Other Nansen Legacy studies identified the importance of rapid ice-change events for the sea-ice conditions in the Barents Sea. These events are often driven by larger scale features as heat transport or loss and are associated with large displacements of the sea ice edge.

Data publications

An important legacy from the Nansen Legacy is also the observational, experimental, and modelling data that can be used for new and different purposes in the future by management and the international science community. Since its start, the project focused on data handling, including harmonizing of sampling methodology, metadata standards, and data publication according to international standards and the FAIR principles (Findability, Accessibility, Interoperability and Reusability). The data manager made various training videos and organized workshops and this paid off: A total of 89 datasets on snow and sea ice observations, biogeochemical parameters, acoustic- and echosounder data, biodiversity data from sea floor, water columns and sea ice, model codes and outputs and a lot more were published and made available in 2023. ■

Organisation

The Nansen Legacy is a collaboration between ten Norwegian research institutions, currently involving over 350 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

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

Tor Eldevik, UiB

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.

Sebastian Gerland, NPI

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

Kai Håkon Christensen, 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 2023. Photo: Charlotte Stark

NANSEN LEGACY BOARD 2023

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Rolf Rødven (AMAP)	Øyvind Rindaldo (Norwegian Coastal administration)	Reference group, user repr.
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Publications

In 2023, 66 peer-reviewed articles were published in international journals, bringing the total number of publications within the Nansen Legacy project to 224. The project aims to adhere to open access publishing to make the generated knowledge freely available for anyone who is interested. In coherence with this, 87% of all publication are available as open access. Key to the Nansen Legacy project is collaboration, and 65% of the articles are co-authored by researchers from at least two of the consortium partners, 20% of the publications are in collaboration with Norwegian institutions that are not part of the consortium, and 56% of the publications are in collaboration with international partners. The list of publications, data sets, and theses from 2023 can be found below.

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Aarflot JM, Eriksen E, Prokopchuk IP, **Svensen C, Søreide JE, Wold A, Skogen MD** (2023) New insights into the Barents Sea *Calanus glacialis* population dynamics and distribution. ***Progress in Oceanography,*** 217, 103106. doi.org/10.1016/j.pocean.2023.103106

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Datasets

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The Nansen Legacy in numbers

7 years

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

1 400 000 km² of sea

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

350 people

In total there are over 300 researchers working with the Nansen Legacy, of which 120 are early career scientists. In addition, 50 persons are involved as technicians, project coordinators, communication advisers and board members.

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.

>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*.

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.

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