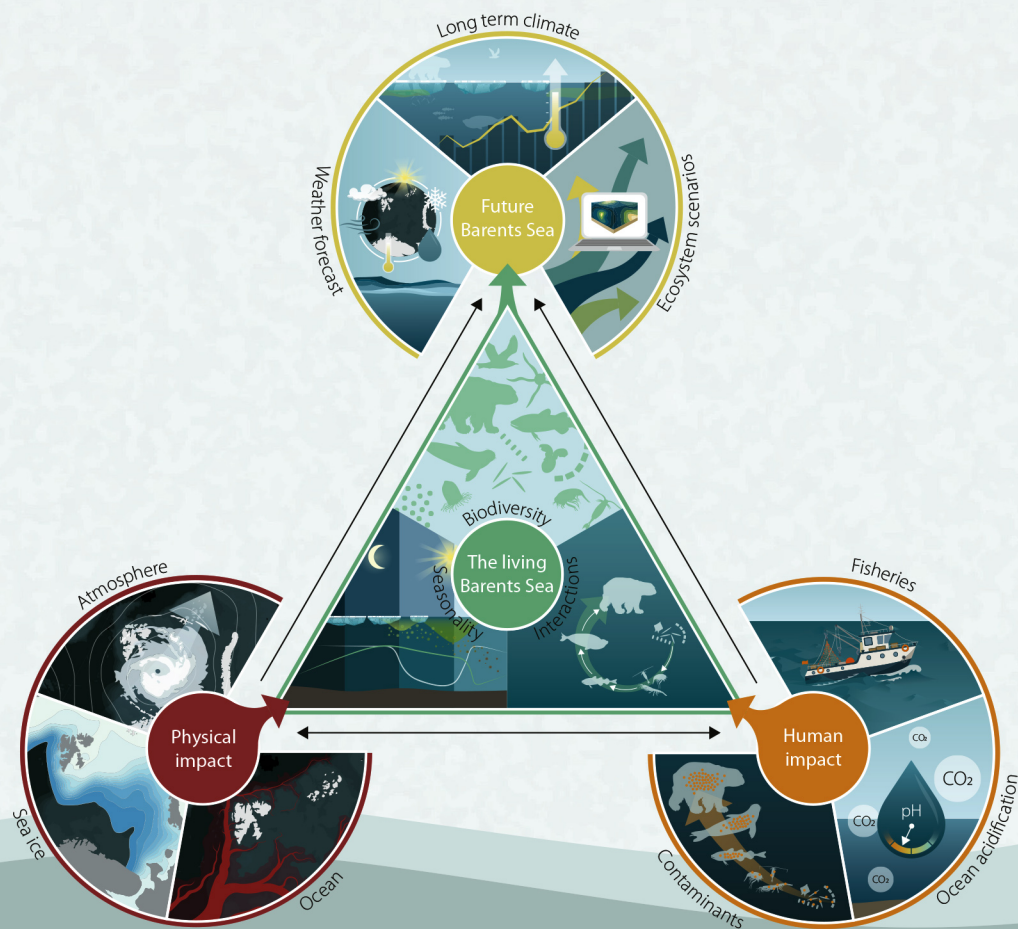


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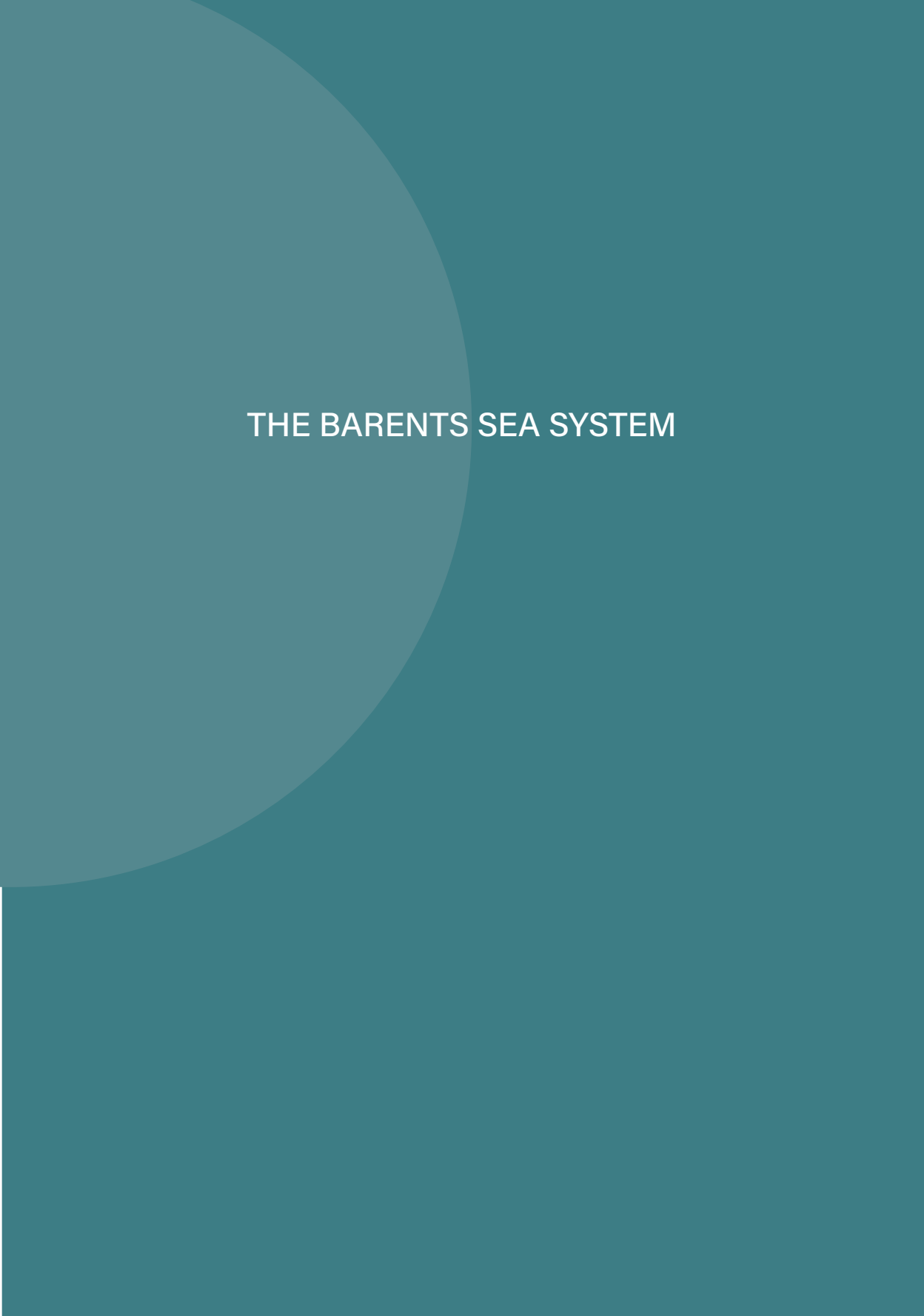
With illustrations by Frida Clossen

The Barents Sea system

Gateway to the changing Arctic



FAGBOKFORLAGET



THE BARENTS SEA SYSTEM

Marit Reigstad, Geir Johnsen, Arild Sundfjord (eds.)

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Preface

As young scientists, the three editors of this book were nurtured on the knowledge about the Barents Sea provided by books that stemmed from the large Norwegian Pro Mare programme that ran from 1984 to 1989. Those volumes compiled what was then known about the Barents Sea ecosystem, focusing on the south-western part, where open water or open drift ice made it accessible to the research vessels available at that time. The *Ecosystem Barents Sea* books (1992 in Norwegian, 2009 in English) taught and inspired a generation of scientists and conveyed important knowledge from the science community to stakeholders.

The time has come to update the compendium of Barents Sea knowledge. The recently completed Nansen Legacy project (2018–2024) faced a Barents Sea that had transformed since Pro Mare. A new research ice-breaker and northwards retreating sea ice permitted the focus of the Nansen Legacy to shift to the less well-known northern Barents Sea. Taking advantage of new technology, we made more and better observations under ice, at different time and space scales, further away from the research vessel, and during times when we were not there ourselves. We could collect data from the Polar Night, a very dark period that turns out to be surprisingly rich in biological activity, from the sea's surface down to the seafloor. Looking at the Barents Sea in these

expanded spatial and temporal contexts has yielded fresh insights into the forcing that drives the changing climate and environment and the responses of the Barents Sea ecosystem now and in the future.

The Barents Sea system – gateway to the changing Arctic has a broader focus than just the ecosystem and it includes observations from all seasons. The nature and dynamics of the larger scale climate system have become more important than ever to grasping the complexities of a rapidly changing marine environment and ecosystem responses to them. These complexities require a more holistic perspective on the ocean system including both larger- and smaller-scale features and processes and thus a more extensive collaboration across disciplines and approaches. This was the ambition of the Nansen Legacy – to bring the Norwegian expertise together to overcome the fragmented understanding that reflected the fragmented research community. People are leaving a bigger mark in the Barents Sea. Locally, fishing, petroleum activities, and shipping are important in the Barents Sea. The region is also impacted by activities at lower latitudes as pollutants, heat, and increased CO₂ are transported with wind and ocean currents to the north. The Arctic is amplifying the higher temperatures seen globally, and the shrinking sea-ice cover and warmer water is altering the seasonally

ice-covered seas dramatically. Knowledge-based management is therefore key to minimising the impacts of human activities on the ecosystem.

The more than 300 Nansen Legacy researchers who explored and investigated the Barents Sea's physical environment and its biota used palaeo-data collected from deep sediment cores, historical data, and new data collected during more than 350 days in the field and from experiments. Different mathematical models let us integrate complex data and zoom out on larger scales and also peer into the future Barents Sea.

The book's contents are organised around the thematic pillars relevant to understanding the larger system. The introduction sets the scene of the topics addressed in the book, before we turn to the environmental drivers that shape the Barents Sea. Those include atmospheric jets, ocean currents, sea-ice dynamics, light conditions, and nutrients. The carbon cycle and ocean acidification are also covered. The next chapter explores the living Barents Sea – biodiversity, production from microalgae to harvestable fish and whales, food webs, and the interactions among the organisms living in the sea ice, in the water column, and at the seafloor. The chapter on human impacts addresses the many ways in which our local or distant activities affect the Barents Sea, where noise and light are pollutants of growing significance.

The new and rapidly advancing technology that allows us to look at, sample, and measure facets of the Barents Sea that were until not long ago beyond scientific reach is the subject of the next chapter. The scale of the data collected during the Nansen Legacy is unprecedented in this part of the

Arctic Ocean, thanks largely to new tools, ranging from a state-of-the-art research vessel to small uncrewed vehicles controlled through cutting-edge robotic and sensor systems. Presenting scenarios of the physical and living Barents Sea in 2050 and at the end of this century, the chapter on the future Barents Sea also describes the modelling tools that generate such projections.

The final chapter explains the processes, agreements, and legal frameworks that handle ocean management in Norway and internationally. The goal of sensibly regulating people's activities – on the basis of up-to-date, integrated knowledge of the ecosystem and insight into the stressors and pressures the ocean is now facing – is to ensure that our children's children – and the generations that come after them – can harvest from a bountiful ocean as rich in diversity as before.

The Barents Sea system – gateway to the changing Arctic synthesises and summarises what we have learned about this part of the Arctic Ocean, rendering this information accessible across the many disciplines involved in ocean science and management. We want to convey this new knowledge to policy-makers, people in industries, other stakeholders, and non-specialist readers who want to learn more about the ocean. With this in mind, methodological details, definitions of some essential terms and concepts, and other material of this nature have been placed in boxes for the interested reader. The many illustrations, created by the gifted science illustrator Frida Cnossen, elegantly communicate complex scientific concepts and environmental processes. The book is also studded with photographs taken by many of the project participants and the photographers who accompanied them. Tai-

lor-made maps produced by the award-winning cartographers in the Norwegian Polar Institute's mapping section are invaluable components of the book's graphics.

Our early scientific interests and careers were strongly influenced by a seminal volume about the Barents Sea that came out more than 30 years ago. We feel privileged in having been given the opportunity to push forward the bounds of this knowledge, which now encompasses a part of the sea

that was once inaccessible, and seasons that were once believed to be of minimal importance. We hereby share this knowledge with what we hope will be a wide readership – not least the up-and-coming generation of scientists. May they be as inspired, captivated, and challenged by the Barents Sea and the Arctic at large as we were, and may they, in their time, find answers to some of the questions about this complex system that we are only just now beginning to ask.



Acknowledgements

This book is a result of a true team effort. A great many people were involved in obtaining and organising the funding for the Nansen Legacy project, collecting data in the field and in the laboratory, running the research ship, analysing results, and writing, illustrating, and quality-controlling this book.

We thank the Nansen Legacy research team, who established new knowledge about the Barents Sea throughout the Nansen Legacy project period. We are also grateful for the effort the book chapter leads have invested in coordinating and synthesising new and existing knowledge into a volume with a potentially wide readership, including non-specialists. The production of the book, the time of many of the authors, and much of the new information presented have been funded by the Research Council of Norway through the Nansen Legacy (project number 276730), in collaboration with the Ministry of Education and Research and all the partner institutions. We thank all the partner institutions for their support during the research project and the book project (in alphabetical order): Akvaplan-niva, the Institute of Marine Research, the Nansen Environmental and Remote Sensing Center, the Norwegian University of Science and Technology (NTNU), the

Norwegian Meteorological Institute, the Norwegian Polar Institute (NPI), UiT The Arctic University of Norway, the University Centre in Svalbard (UNIS), the University of Bergen and the University of Oslo. Mats Granskog (NPI) acknowledges the in-part support by a fellowship at the Hanse-Wissenschaftskolleg Institute of Advanced Study (HWK) at the time of the completion of this book.

We thank the logistics team and the crews of RV *Kronprins Haakon*, RV *G.O. Sars*, RV *Kristine Bonnevie*, and RV *Helmer Hanssen* for skillfully tackling the difficult challenges that the research cruises encountered in the harsh environment of the Arctic. Their contribution to successfully collecting so much new data – through all seasons and over several years – cannot be overestimated.

We are grateful for the contributions from our art and map team. We thank Frida Cnossen (Nansen Legacy/UiT) for her creative flair and hard work, which resulted in beautiful and captivating illustrations. We thank Oddveig Øien Ørvoll and Anders Skoglund (NPI) for making the book's base map as well as many complete map figures. We thank Anca Cristea (NPI) for processing the sea-ice data that were used in the map figures.

The book is also nicely illustrated with the many photos we have been allowed to

use. A special thanks to the photographers Fredrik Broms (northernlightsphotography.no), Christian Morel (christianmorel.net) Rudi Caeyers (UiT), and Peter Leopold, in addition to the many researchers that have provided photos to illustrate the Arctic environment and life. We also acknowledge the Mareano programme, which has produced and made available a number of great images used in the book.

The editorial support for the book project has been truly invaluable. Helle V. Goldman (NPI) massaged the text to make sure it was readable, meaningful, enjoyable, and consistent across the chapters, with some help from Gunn Sissel Jaklin (NPI). Anna Miettinen (UiT) assembled and edited the references and managed all the pictures and illustrations in the book.

We thank Fagbokforlaget for excellent cooperation and guidance throughout the publishing process.

We would also like to acknowledge our debt to Egil Sakshaug, who passed away as the work on this book drew to a conclusion. His work on the first two books about the ecosystem of the Barents Sea was visionary. We also thank Paul Wassmann, who proclaimed, early in the Nansen Legacy planning, the need for an updated Barents Sea book as a project deliverable. Paul took part in the preliminary stages of outlining the book.

The editors

Marit Reigstad
Geir Johnsen
Arild Sundford

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The Barents Sea: the big picture

Marit Reigstad, Geir Johnsen, Arild Sundfjord

This chapter introduces the Barents Sea and provides an overview of, and introduction to, the topics included in the book. The Barents Sea is greatly influenced by its surrounding seas. And changes in the Barents Sea have impacts far beyond its own neighbourhood. We introduce the larger Arctic region that the Barents Sea is part of, and the main factors driving variability and change, including activities such as fisheries and the petroleum industry. We then

discuss the knowledge needed to obtain a complete understanding of this interconnected system – knowledge that is necessary for the best possible management of human activities in the area. The chapter also gives an overview of the history of collecting observations to build a progressively more complete understanding of the Barents Sea, thus placing our present knowledge in a historical context that spans several hundred years.

1.1 A shelf sea in the Arctic Ocean

Arild Sundfjord, Marit Reigstad, Geir Johnsen

At 70–80°N, the Barents Sea is the northernmost of the relatively shallow seas on the Arctic continental shelves. It is also the Arctic shelf sea where commercial activities are concentrated. These have been confined mainly to the south-western Barents Sea, but activities are moving northwards as the sea ice retreats. Recent research is shedding light on a part of the Barents Sea that has been difficult to reach and therefore poorly understood.

1.1.1 The regions of the Arctic Ocean

Sandwiched between the cold, ice-covered interior Arctic Ocean and the warmer, ice-free North Atlantic, the Barents Sea is

strongly influenced by two very different climatic regimes while acting as a gateway between them (Chapter 2). The Barents Sea can be described as an inflow shelf: Atlantic Water flows into and through it, from the south-west to the north-east, feeding the interior Arctic Ocean with heat, salt, nutrients, carbon, and organisms – and pollution from sources further south (Fig. 1.1). In this respect, the Barents Sea is different from the adjacent shelf seas along the Eurasian continent – the Kara, Laptev, and East Siberian seas – which can be considered interior shelf seas that are predominantly affected by local atmospheric processes and river runoff from land. With an average depth of 230 m, the

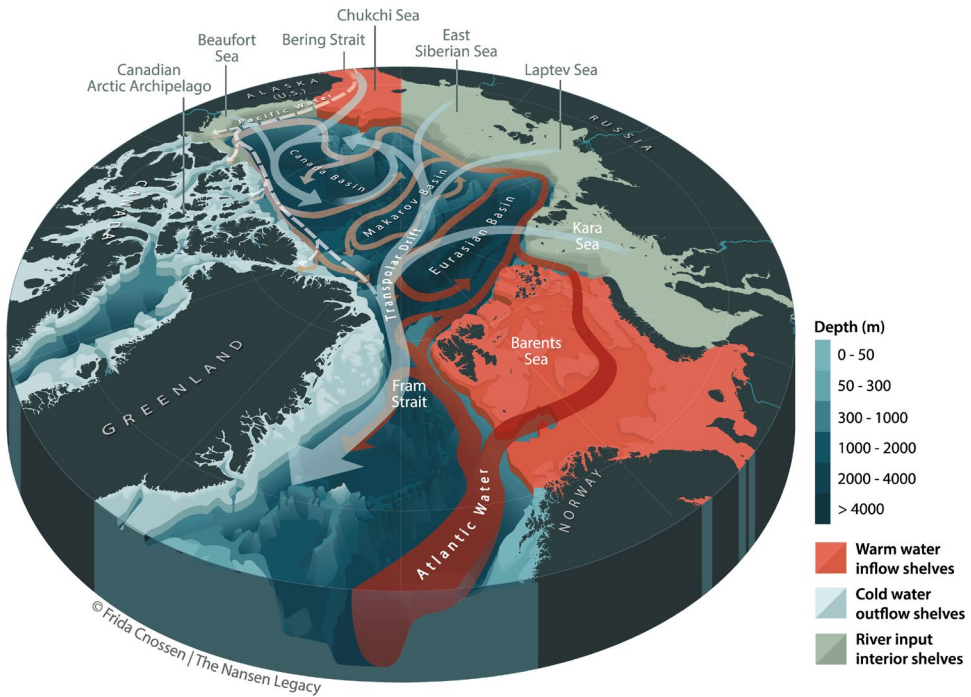


Fig. 1.1. Overview of the main current pathways into, within, and out of the Arctic Ocean. The two main inflow shelves, the Barents Sea and the Chukchi Sea, are highlighted with orange shading. (Illustration: Frida Cnossen, Nansen Legacy. Modified version of a figure by Polyakov et al., 2012.)

Barents Sea is the deepest of the Arctic shelf seas. The Atlantic Water that enters the Arctic Ocean via the 2500-m-deep Fram Strait and the Barents Sea follows the continental slope eastward but is located too deep to make its way onto these shallower interior shelves regularly or consistently.

The only other Arctic inflow shelf sea is the Chukchi Sea. Averaging 80 m deep, it is shallower than the Barents Sea and receives relatively fresh and nutrient-rich Pacific Water through the Bering Strait. The Beaufort Shelf, east of the Chukchi Sea, can be considered an interior shelf, but it is considerably narrower between land and the

continental slope compared to the interior Eurasian shelves. Water masses and sea ice exit the Arctic Ocean predominantly through the waters of the Canadian Arctic Archipelago and the East Greenland shelf. Covered by ice most of the year, these outflow regions have large quantities of melt-water from the interior Arctic Ocean and from the local melting of sea ice as it travels southwards. The Barents Sea also receives sea ice from the adjacent Nansen Basin (part of the Eurasian Basin) and the Kara Sea. Most of this ice melts in the Barents Sea, contributing to the strong seasonal stratification in the northern part of the sea.