Whither the Arctic Ocean?

Research, Knowledge Needs, and Development en Route to the New Arctic

Paul Wassmann (Ed.)

BBVA Foundation

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FOREWORD

CARLOS TORRES VILA

President, BBVA Foundation

Climate change is one of the greatest disruptions in human history and the melting of ice in the Arctic Ocean is the clearest evidence of this reality. Since 1979, data from NASA's satellites show that the Arctic sea ice has been reaching its minimum each September at the end of the summer melt season. The Arctic sea ice is now declining at a rate of 13.1 percent per decade.

Two decades ago, the Intergovernmental Panel on Climate Change introduced the idea of tipping points. Tipping points in the climate system are thresholds that, when exceeded, can lead to large and irreversible changes in the state of the system. Despite existing scientific evidence indicating that thresholds are approaching and/or being crossed in the climate system, government interventions to address tipping points have so far been predominantly reactive.

However, 2020 has proved a turning point in the fight against climate change. The massive fiscal response to the coronavirus crisis worldwide has been key to moving from awareness to climate action. Governments and the private sector have turned commitments into policies and plans, catalyzing the transition towards a net zero economy.

The COVID-19 pandemic has been an extraordinary test run for climate change and is showing that international cooperation is key to overcoming global challenges. These challenges that go beyond borders require a collective response. Both coronavirus and climate change are urgent problems that impact everyone, without exception. Unlike with the coronavirus, to which we will eventually build immunity, the impacts of climate change will worsen over time. Climate change should be considered a planet-wide emergency and be seen as a clear and present danger, and not as a diffuse or future threat.

The multi- and cross-disciplinary research set out in this volume is an extraordinary approach to the profound impact that certain tipping points, such as the warming of the Arctic Ocean, can have on the climate of the whole planet and in people's lives.

The Arctic is among the parts of the world most influenced by climate change and its melting ice is a global-scale concern. It is increasingly clear that the interconnectedness of the Arctic with lower latitudes will have unprecedented impacts and consequences across a range of economic, societal, and geopolitical challenges. A new Arctic is already emerging and, if global temperatures keep rising at their current pace, the transformation to an unrecognizable climate system could reach completion before the end of this century.

At BBVA, sustainability is at the core of our strategy and aligned with our purpose: "To bring the age of opportunity to everyone." We aim to help our clients and society in general to transition to a sustainable future. In doing so, we have taken a comprehensive approach to sustainability challenges by including not only climate change, but also other environmental and social challenges in line with the United Nations Sustainable Development Goals.

As part of this effort, the BBVA Foundation plays a fundamental role in our strategy to promote a better future. The defense of sustainability is one of the BBVA Foundation's priorities, which it pursues by supporting research in environmental sciences, and promoting scientific excellence and actions in defense of biodiversity, as well as by disseminating knowledge about the health of our planet. *Whither the Arctic Ocean?* is a new contribution to these goals and is aligned with the Foundation's objectives and those of the entire BBVA Group.

For over a decade, the BBVA Foundation has promoted knowledge by addressing the challenges contemporary society is facing, and by rewarding world-class research through the prestigious Frontiers of Knowledge Awards.

Some past prize winners have addressed aspects closely related to the problem covered in this book. For example, Richard Alley's research has analyzed the behavior of ice and its implications for abrupt climate changes. Annie Cazenave, John Church, and Jonathan Gregory have documented the potential impact of rising sea levels as a consequence of the polar melt, and Marten Scheffer has investigated the tipping point phenomenon, charting the gradual and potentially irreversible changes in ecosystems impacted by human action.

This book edited by Professor Wassmann is part of the Foundation and the BBVA Group's strong commitment to sustainability. Global society must become aware of the consequences that Arctic warming can unleash on the entire planet, and this work will undoubtedly contribute to further attention and understanding.

INTRODUCTION

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Climate change in the Arctic Ocean (AO) has stirred a remarkable surge of interest and concerns, including among non-Arctic states, non-state actors and the general public. Lack of long-term scientific observations makes it difficult to assess whether Arctic changes statistically represent a new climate, but extremes have become routine in what most consider as an emerging "new Arctic" (e.g., Landrum and Holland 2020). In light of this, the present volume brings together the personal viewpoints, impressions and suggestions of a range of Arctic researchers with a multi- and transdisciplinary background.

The authors come from the entire expanse of the pan-Arctic region, which is by far the world's most climatically impacted. Their experience derives from a wide scope of endeavors: politics, management, industry and the entire range of basic humanistic and natural science research. What the authors have in common is their work in and for the Arctic and their awareness regarding the multi- and transdisciplinary nature of the drive to understand and manage climate change. "Whither are we bound?" would be a typical phrase in older English that covers the essence of the authors' concerns. Attempting to answer this demanding question is the ultimate goal of this volume. As with all complex systems, there is not one answer, but several that embrace uncertainty and skepticism.

DEFINING AND FRAMING THE SYSTEM

In order to comprehend a multifaceted system, one has to define what is considered "the system," which is a segment inside a continuity. And to accomplish that, one has to apply "framing." Framing is a key component of the study of nature or other systems. It is related to agenda-setting, the process by which problems and alternative solutions gain attention. In our case the frame is the central AO, a quasi-circular Mediterranean-type ocean. The essential nature of framing procedures is well described by Albert Einstein's oft-quoted remark that "we cannot solve our problems with the same level of thinking that created them." Rather, we have to rise above it to the next level. Traditionally we investigate the regional question in the High North, and the next level is then the AO and its hinterland as a system. This perspective appears in various aspects that the book's chapters explore.

As in pointillist painting, the reality of the Arctic manifests itself as the interplay of various facets; here through the medium of the essays. The answer to the question "Whither the Arctic Ocean?" becomes clearer with increasing distance and through the interplay between the points, i.e., by looking simultaneously at all the essays. There is no definitive answer to "Whither the Arctic Ocean?", but one may appear in appealing, but shimmering vagueness out of the distance required to see where our multi- and transdisciplinary understanding might find a common home (photo 1).

The starting point for the book is the need for cooperation between traditionally separate fields of natural, social and political science, social anthropology and management perspectives. In the Arctic, they all take their motivation from the record-high decrease in the extent and thickness of sea ice, surface water warming, invasion of boreal species and changes in coastal dynamics.

Of particular significance is the borealization of inflow shelves, i.e., the northwards expansion of boreal to the detriment of Arctic species. This supports not only structural change over large spatial scales in ecosystem function and composition at high latitudes. It also increases the economic interests in the region and promotes a strong demand for ecosystem-based management, and wise political compromises and decisions. In concert with increased access to mining, tourism and transport, borealization results in potential conflicts in the Circumpolar North. A composite of local populations, Indigenous and non-Indigenous, engirdles the AO, and the political, climatological and economic challenges of the circum-Arctic are highly variable. Living in peace and having agreed to solve challenges on the basis of the Law of the Sea and negotiations, the Arctic nations and coastal states address the highly variable realities of the AO and adjacent lands with dedication.

MULTIDISCIPLINARY CHALLENGES

Against the background of the intrinsic demand for multi- and transdisciplinary understanding of the pan-Arctic region that is echoed by the Arctic states, research councils, the EU, UNESCO and the UN, it is surprising that it turned out to be difficult to find a publisher for this book. Many prominent science publishers find homes and subject editors for distinct research fields, but what the world subjected to climate change demands most are multi- and transdisciplinary approaches that encompass a sound base

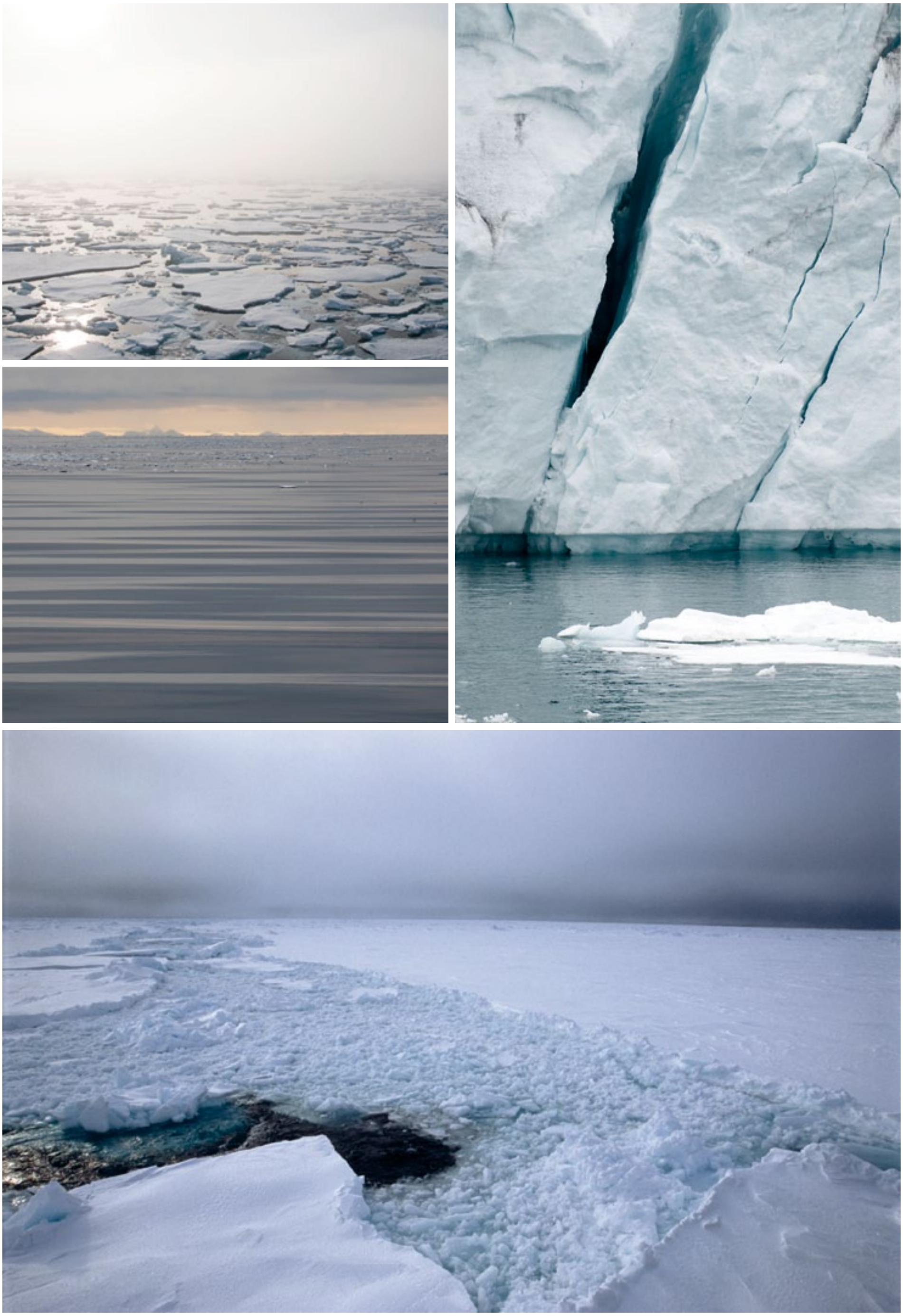

Photo 1: Four fascinating images of Arctic Ocean landscapes. Glacial front and various aspects of the expanse of the marginal ice zone.

for sustainable ecosystem management and human living conditions and a sound base for economic decision-making. Obviously such volumes do not easily find their pathway to publishers, and the question may be raised as to whether the latter are sufficiently familiar with society's need for multidisciplinary and integrated approaches. In order to stimulate our reflections on the state of the environment and its implications for policy, the Environmental Science series of the BBVA Foundation came to our aid, facilitating the effort to alert society to the need to conserve and wisely manage the complexities of our Arctic environment (photo 2).

The unprecedented changes that have already taken place, let alone those that await us in the foreseeable future (Overland 2020; Landrum and Holland 2020), have alarmed the scientific community dedicated to the AO (e.g., Evengard et al. 2015). Part of the significant unease felt is nourished by the economic interests of a resource-hungry and transportation-dedicated world in the Arctic—a scenario clearly illustrated by recent meetings of the Arctic Council. In the center of a big hall the eight Arctic nations convene, surrounded by 38 observing non-Arctic states and intergovernmental, interparliamentary and non-governmental organizations. The world looks with interest and expectation towards the Arctic. Our not-up-to-scratch understanding of the relevant processes and our lack of long-term data series render prediction of the future of the Arctic impossible, and even projecting is a real challenge. It is no surprise therefore that many researchers have reflected on the physical and ecological future (e.g., Meier et al. 2007; Duarte 2008; Wassmann 2015), the financial and political interests in exploiting Arctic areas (e.g., Young 2009; Smieszek et al. 2016), and the condition of the Indigenous population (e.g., Nakashima et al. 2012). The present essays express the personal commitment and views of centrally placed scientists that cover the entire range of scientific, political and management challenges in the AO.

The author consortium examines the expanse of change that is now taking place and scans the horizon for future challenges and solutions. The essays deal with natural science, social anthropology, technology and new business, food security, politics and legal matters, Indigenous perspectives and the empowerment of locals. Indirectly the volume touches on humanity's greatest challenges: the ingrained desire to plan into the future on the basis of continuity and linear or curvilinear model perspectives. The development of nature and life comprises a sequence of predictable epochs with stable states, potentially separated by unforeseen tipping points that result in phase changes (e.g. Duarte et al. 2012). Tipping points are in general not part of human preparedness and thus humanity, over and over again, is overwhelmed by shocks which, with hindsight, are frequently rationalized as inevitable (Wassmann and Lenton 2012). Is it possible to see and prepare for the inevitable before being overpowered by it? (photo 3).

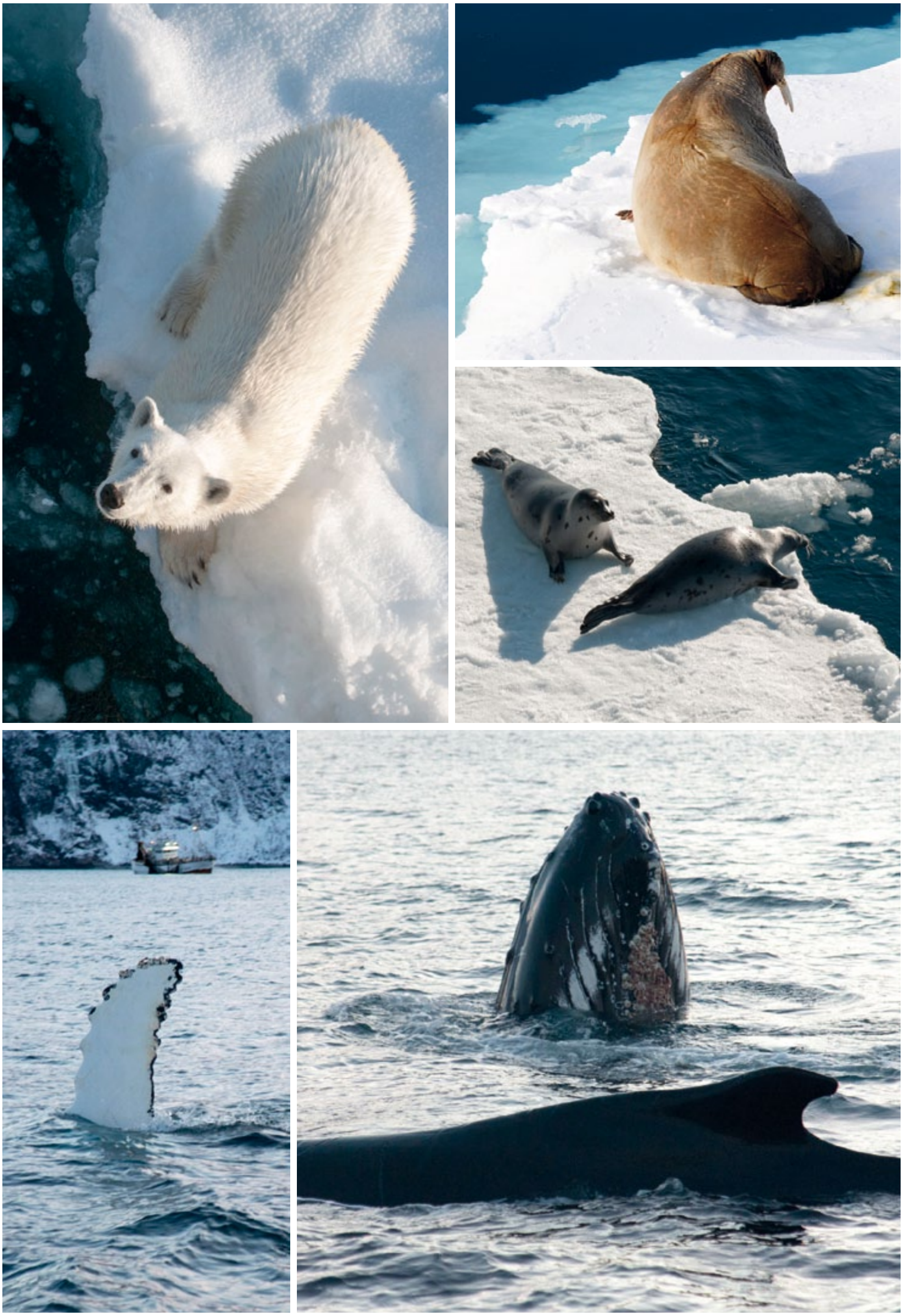

Photo 2: Large organisms that accumulate lipids are an enigmatic characteristic of the Arctic Ocean. Polar bear, walrus, seals, and whales.

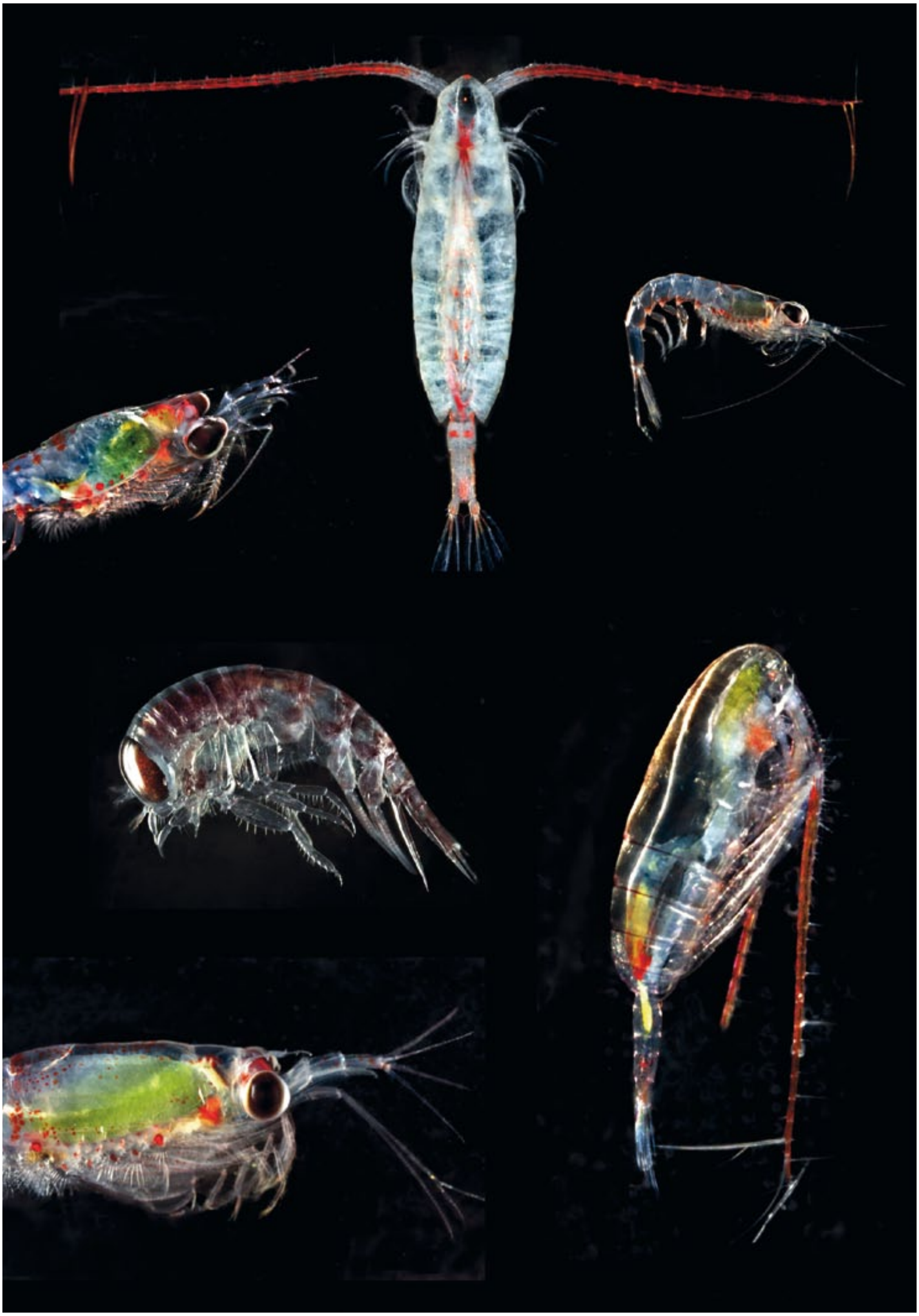

Photo 3: Colorful and varied plankton organisms play an important role as food for large organisms in the Arctic Ocean. *Top and lower right*, copepod; *upper and lower left*, krill; *upper right*, mysid; *center left*, amphipod.

A RESILIENT ARCTIC OCEAN?

Because the AO has always been subject to great climatic variability, its ecosystems have, so far, had a robust resilience enabling them to return to a new equilibrium state when perturbed. However, resilience is now diminishing due to the magnitude of climate change in the Anthropocene (Overland 2020). Climate change may expose the AO to a shock which it has to react to by finding a new stable state, restoring the hitherto stable state, or entering a decades-long period of variability. At some point a given external shock may force the system beyond its threshold (tipping point) into a new stable equilibrium. Nobody knows if a new state will provide the ecosystem and environmental services that today's human society is accustomed to receiving. Nor do we know if a new state will have overall positive or negative consequences for humans. The greatest challenges appear to be the variability in weather extremes down to the mid-latitudes of the Northern Hemisphere, changes in carbon flux, food security, and changes in natural food availability for Indigenous populations. Unprepared, the future may involve black swan events; a metaphor describing an unfamiliar event that comes as a surprise and has a major effect.

This volume does not claim to cover all the challenges of the future AO, let alone the approaching tipping points, in a balanced and exhaustive manner. But it represents an attempt to grasp the reality of the AO in a multi-, transdisciplinary and pan-Arctic manner. Somehow the views of the disciplines that come together here may create the basis for the sustainable future of both Arctic nature and man. We have to search for the hidden pathways to a sustainable AO future. Into what state will the AO develop? Whither are we bound? We must prepare for the probable while embracing surprise. And the basis for such preparation and acceptance must be strictly systemic and thus multi- and transdisciplinary.

A DECADE OF OCEAN SCIENCE FOR SUSTAINABLE DEVELOPMENT AND THE PAN-ARCTIC REGION

Recently the United Nations has proclaimed a Decade of Ocean Science for Sustainable Development (2021-2030)[1] to support efforts to reverse the cycle of decline in ocean health. The Decade unites ocean stakeholders worldwide behind a common framework that will ensure ocean science can fully support countries in creating improved conditions for sustainable development of the oceans. The Decade is embracing a participative and transformative process so that scientists, policy makers, managers, and service users can work together to ensure that ocean science delivers greater benefits for both the ocean ecosystem and for society. First, the Decade en-

[1] See https://unesdoc.unesco.org/ark:/48223/pf0000261962.

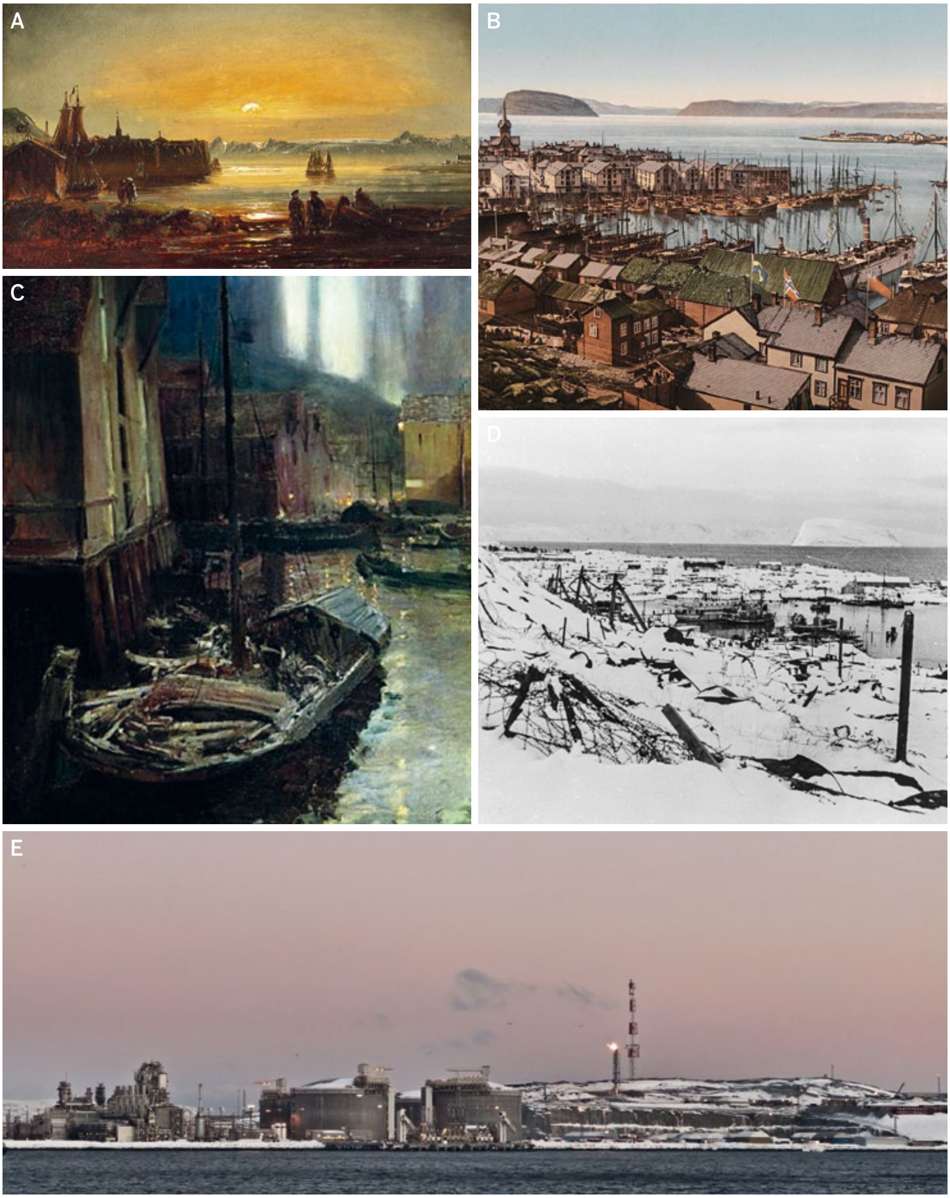

Photo 4: Five depictions from the Arctic town of Hammerfest. These images illustrate how circum-Arctic settlements are subjected to the harshness and variability of the Arctic Ocean. A. presents a romantic depiction by Norwegian painter Peder Balke (1851). B. shows a colored photograph of the city from the period 1890-1900 (photographer unknown). C. is a painting by the Russian artist Konstantin Korovin, depicting the harbor front and sailing vessels under northern light (1894/95). D. shows Hammerfest after its total destruction by the German Army in 1944. E. depicts the industrial island Melkøya, the endpoint of the undersea pipeline that transports natural gas from a gas field in the Barents Sea. The gas goes through the 168 km long pipeline to the processing station on Melkøya, where it is converted into liquefied natural gas.

courages a more inclusive and participative approach in designing and executing science. Second, the Decade sets out to build reinforced dialogues (science-policy interface as well as multidisciplinary approaches, bringing new disciplines and integrating natural, social and engineering sciences while giving value to traditional/Indigenous knowledge). Third, the Decade promotes knowledge and information that should be more equitably shared around the world (closing the knowledge gaps between countries, balancing knowledge systems and taking into consideration the needs of coastal communities).

In all modesty we can state that the intentions and plans of the Decade of Ocean Science for Sustainable Development fit well into the aims of a multidisciplinary volume like ours, which asks to what place or state the rapidly changing AO is heading? This book encourages inclusive and participative approaches in designing and executing science, argues in favor of building reinforced dialogues, and promotes knowledge and information that is equitably shared around the pan-Arctic. Adaptation strategies and science-informed policy responses to global change are urgently needed; not least in the AO, where global warming is three times higher than the world average and where some of the research results published today reflect the world of yesterday. Scientific understanding of the AO's responses to pressures and management action is fundamental for sustainable development, not only for the Arctic, but for the entire Northern Hemisphere. Ocean observations and research are essential to predict the consequences of change, design mitigation and guide adaptation, in particular for the people of the Arctic that have the coastal zone as their home. The current volume can thus be considered as a timely contribution and forerunner of the Decade of Ocean Science for Sustainable Development, focusing upon the AO.

ACKNOWLEDGEMENTS

This suite of essays came into being thanks to the enthusiasm of the volunteering authors. In concert they merged their efforts into this publication. The support and financial assistance of the BBVA Foundation gave rise to and facilitated this book. We thank the Foundation for its careful and professional editing, in particular Cathrin Scupin and Jose Manuel Reyero. Rudi Caeyers helped with some of the figures. This publication benefited from support by UiT The Arctic University of Norway. The scope of the book and this Introduction draw on the work of the Arctic SIZE research group (http://site.uit.no/arcticsize/).

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CHAPTER 1

THE ARCTIC: TOMORROW'S CHANGES... TODAY! THE CENTRALITY OF THE ARCTIC AND NORTHERN OCEAN IN THE CONTROL OF ARCTIC CLIMATE AND GLOBAL-SCALE CHANGES

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UiT The Arctic University of Norway, Tromsø

The changes in the Arctic have already had unprecedented impacts and consequences in lower latitudes across a range of economic (Alvarez, Yumashev and Whiteman 2020), environmental (National Research Council of the National Academies 2007), societal (Stephen 2018) and geopolitical (Tingstad 2018) realities, most notably rising sea levels, increases in extreme weather and substantial changes in international geopolitics. The Arctic and the northern oceans drive global-scale changes that accelerate and amplify changes within the Arctic (IPCC 2018). However, those changes in the Arctic drive unprecedented changes in the northern hemisphere (AMAP 2017) and beyond, affecting the sustainable future of both the High North and globally, including:

- The loss of Arctic sea ice is changing the character of the Arctic region,
- Global ocean circulation controls the High North environmental envelope,
- Land ice melting is controlled by ocean and atmospheric temperatures, and
- Ocean-atmospheric interactions control Northern Hemisphere weather.

There are significant scientific and national-interest challenges. The Arctic and the North Atlantic-Arctic regions are changing rapidly as a result of global climate change. Over the recent past, warmer Arctic atmospheric and ocean temperatures have led to unprecedented Arctic Ocean sea-ice deficits (75% loss of sea-ice volume in 2019) (Overland et al. 2019). Future changes in the Arctic are projected to occur at least twice as fast as changes further south, leading to less snow and sea ice, thawing permafrost and melting glacial ice, and altered ecosystems, all driven by projected annual mean Arctic surface temperature increases of 9°C (Overland et al. 2019) towards the end of the 21st century. This projection is described by the IPCC as the scenario without substantial reductions of global carbon-based fossil fuel emissions.

Globally, the ocean is the largest solar energy collector on Earth (Dahlman and Lindsey 2020). This tremendous ability to store and release heat over long periods of time

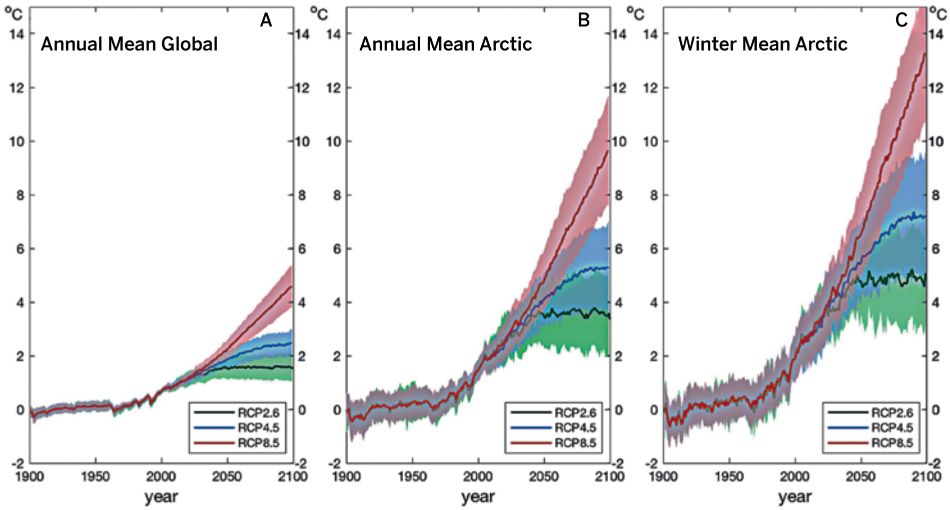


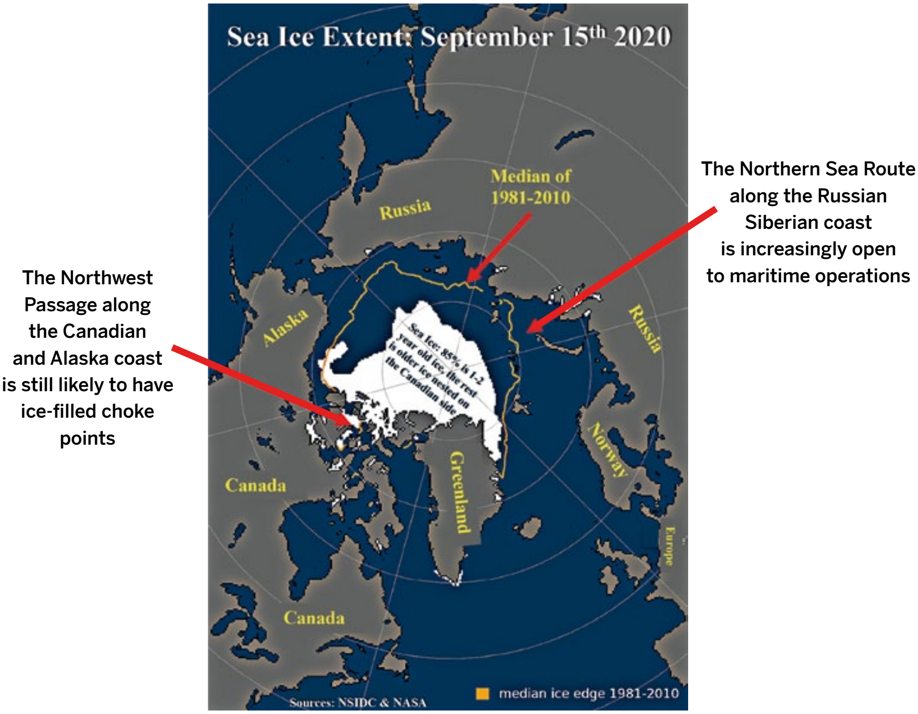
Figure 1.1: Projections of annual global and Arctic mean surface air temperatures. Projections (60–90° N) are derived from the average climate as depicted in IPCC scenarios and expressed as departures from the mean of 1900–1950. *Source:* James Overland NOAA.

gives the ocean a central role in the control of the Earth's climate system (Rizzoli and Stone 2009) (figure 1.1). The IPCC and the preponderance of the peer-reviewed scientific literature have concluded that climate change is mainly the result of an energy imbalance in Earth's climate system caused by the rising concentrations of heat-trapping gases from human activities. About 93% of this energy imbalance (Cheng et al. 2019) is stored in the ocean as internal energy (i.e., heat). Recent scientific observations show the warming of Earth's oceans increasing over the past few decades (Dahlman and Lindsey 2020), contributing, along with a warmer atmosphere, to increases in rainfall intensity, sea levels, and coral bleaching, declining ocean oxygen levels, declines in glacial ice sheets in polar regions, and, most notedly, the opening coastal seaway in the Arctic Ocean. These unprecedented changes in the Arctic have significant consequences for the nations within the Arctic and globally.

THE LOSS OF ARCTIC SEA ICE IS CHANGING THE CHARACTER OF THE ARCTIC REGION

While mean global surface temperatures have only increased by about 1°C since 1880,[1] two-thirds of the warming has occurred since 1975, at a rate of 0.15°C to 0.20°C per decade (NASA 2020a). The mean ocean surface temperature increases over the same pe-

[1] Data from NASA/GISS Time Series: 1884 to 2019.



Map 1.1: Sea ice extent, September 15, 2020. The sea ice minimum extent in September is decreasing at a rate of ~12% a decade since 1950, and now ~80% of the 1950 volume of sea ice is permanently gone.

riod are about twice this for the Arctic Ocean, which is contributing to the melting of the Arctic Ocean ice masses. According to NASA (2020 b), Arctic sea ice is now declining at a rate of 13.2% per decade (map 1.1), leaving more open waters in the late summer and early fall across the Arctic Ocean.[2]

Opening Arctic Shipping Seaways: Most cargo shipping activity (Congressional Research Service of the US Congress 2020) is currently along the Northern Sea Route (NSR),[3] largely to transport natural resources from the Arctic or to transport general cargo and supplies to development sites and communities. The bulk of shipping is liquefied natural gas (LNG), with some oil, and for the support of natural resource development, mostly along the Russian coast (Bellona Foundation 2020). Shipping on NSR was

[2] There are localized regional effects from these increased temperatures in the Arctic Ocean, where NASA data indicated that air temperature over the entire land mass of Greenland was higher by more than 20 degrees Celsius on April 15, 2019.

[3] The Northern Sea Route is a shipping route officially defined by Russian legislation as lying east of Novaya Zemlya and specifically running along the Russian Arctic coast from the Kara Sea to the Bering Strait. The entire route lies within Russia's exclusive economic zone.

up 40% in 2019 (Arctic Today 2019), the major share of which went to LNG produced by the Russian company Novatek,[4] with 16 million tons shipped in 2019. There has also been a modest increase in tourism to the Arctic Ocean. Overall, compared to global shipping, the number of ships operating on the NSR is a single digit percentage of global shipping.

The Opening of the Seaway is Facilitating Coastal Socio-Economic Development: Development and related economic investment within the Arctic region is intensifying. As the sea ice in the Arctic Ocean retreats, national governments (e.g., Russia) and the private sector are increasingly focusing their engagement and finances on infrastructure in the region. New ports and harbors, mines, gas and oil pipelines, roads, railways, coastguard facilities, and airports to serve the Arctic are materializing at accelerating speed. Much of this development is taking place incrementally, but as it proceeds there are consideration needs that have to be developed, raising issues concerning the physical, environmental and societal impacts of these changes.

There is also the ancillary policy question of how they can, or even should be managed and optimized for the benefit of local and Indigenous Arctic communities (Sherwin and Bishop 2019). The Russian Federation is emerging as the early developer of the civil socio-economic infrastructure, and, more recently, as a military presence (Chatham House 2019) along the Russia Arctic coasts (International Centre for Defense and Security 2019). Finland, Norway, Canada and the United States are each proposing infrastructure investments. China is increasing its Arctic region economic opportunities and territorial challenges as it seeks a greater role in the Arctic through its "Polar Silk Road" initiative,[5] even though China is not a coastal Arctic nation.

Access to Coastal Arctic Natural Resources Enables Development: The potential for Arctic-based natural resources development is based on the availability of (a) Arctic hydrocarbons (Lindholt and Glomsrød 2015), including natural gas (30% of global) and oil (13% of global), and (b) hard minerals (Lindholt and Glomsrød 2015) including palladium (40% of global), nickel (22% of global), diamonds (20% of global), platinum (15% of global), zinc (10% of global), and rare earths (25% of global). Some of these are essential to the electronics industry, as the Arctic contains rare minerals critical for the manufacture of e.g., cell phones and handheld pads.

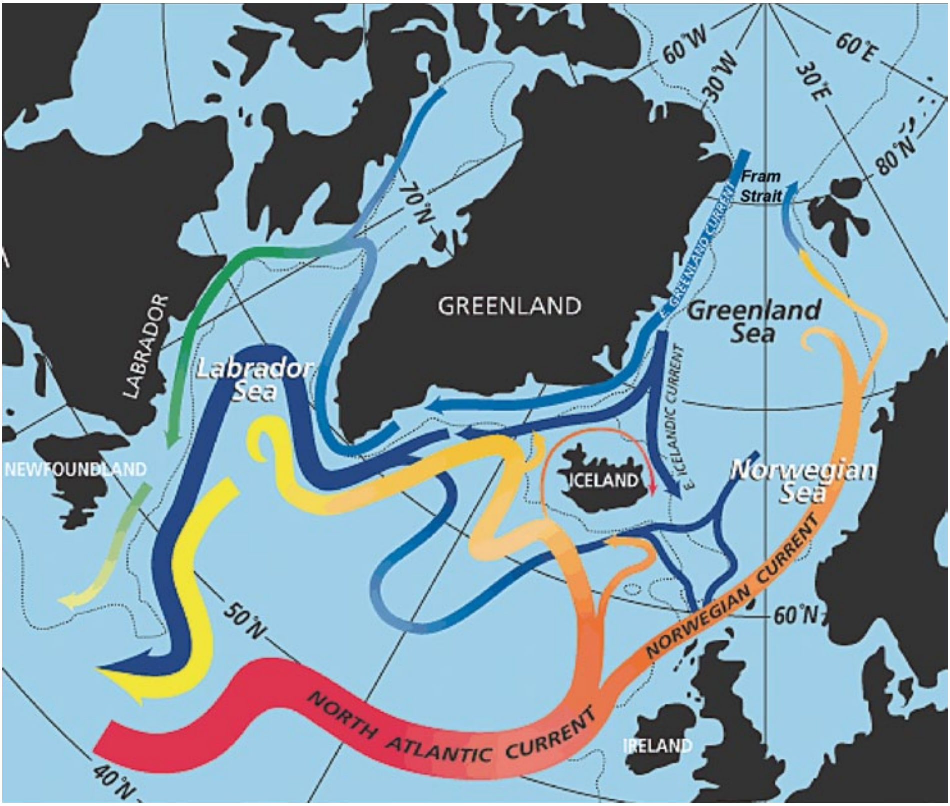
[4] Russia is fostering the LNG race with the support of a $21 billion Arctic LNG-2 project. https://www.reuters.com/article/us-russia-energy-novatek-lng/russia-ups-lng-race-with-green-light-on-21-billion-arctic-lng-2-project-idUSKCN1VQ0IH.

[5] In January 2018, China released a white paper setting out its policies and position on the Arctic. For an analysis of this document, see "China's Arctic Policy and the Polar Silk Road Vision." https://arcticyearbook.com/images/yearbook/2018/Scholarly_Papers/24_AY2018_Kong.pdf

GLOBAL OCEAN CIRCULATION CONTROLS THE HIGH NORTH ENVIRONMENTAL ENVELOPE

Global-scale interconnected ocean circulation, known as the "great ocean conveyor" (Broecker 2010), or, more scientifically, the meridional overturning circulation (MOC/AMOC) (Frajka-Williams et al. 2019) is a system of surface and deep currents encompassing all ocean basins. It transports large amounts of water, heat, salt, carbon, nutrients and other substances around the globe and connects the surface ocean and atmosphere with the huge reservoir of the deep sea (map 1.2). As such, it is of critical importance to the global climate system and provides significant warming to the nations of the North Atlantic oceanic region.

The North Atlantic ocean circulation appears to be disrupted**.** As Arctic ice melts, the Arctic Ocean is being flooded with fresh water, which in turn affects oceanic circula-



Map 1.2: North Atlantic meridional overturning circulation, AMOC. The AMOC is an integral part of global oceanic circulation, as it transports a substantial amount of stored heat from the tropics and the Southern Hemisphere that warms northern Europe. *Source:* Widely Used In Science Literature.

tion patterns of ocean water, and this freshwater influx and other climate change effects are projected to have profound impacts on global ocean circulation. Circulation of the Atlantic Ocean (Atlantic meridional overturning circulation [AMOC]) plays a key role in regulating the climate on a global level, and recent research indicates that the Atlantic's circulation currents have declined in strength by 15% since the mid-20th century (Thornalley et al. 2018), its weakest point in 1,600 years (Graham 2018).

The potential weakening of the Gulf Stream waters in a part of the North Atlantic (AMOC) is of profound importance to Western Europe and the eastern provinces of Canada, as it releases heat to the atmosphere and warms these regions of the North Atlantic (Martin-Garcia 2019). Most of Western Europe, including some parts of the Euro-American Arctic, is currently of the order of 6°C to 8°C warmer (Martin-Garcia 2019) than it would be without the AMOC, due to the heat that it releases. Any reduction of the heat from the AMOC will proportionately cool Western Europe and the eastern provinces of Canada.

There remain important, unresolved scientific questions about the sensitivity of the AMOC to anthropogenic warming. Rapid Climate Change–Meridional Overturning Circulation and Heatflux Array (RAPID/MOCHA)[6] monitoring programs are monitoring the strength of the AMOC/Gulf Stream. The Overturning in the Subpolar North Atlantic Program (OSNAP) research study is monitoring the overturning system in the subpolar North Atlantic (Lozier et al. 2019). These programs have provided much insight into the factors affecting the AMOC. However, there are significant outstanding questions that need to be resolved to determine the role of anthropogenic warming of the MOC/AMOC system and its long-term consequences for cooling Western Europe and the eastern provinces of Canada (Graham 2018). Keffer and Holloway summarized this reality well some years ago, stating: "An outstanding problem in the oceanic sciences is the rate of heat and freshwater transport from the equator to the poles, for it is this transport which powers the Earth's weather and climate system." (Keffer and Holloway 1988).

LAND ICE MELTING IS CONTROLLED BY OCEAN AND ATMOSPHERIC TEMPERATURES

Ice is melting at an unprecedented pace (Mouginot et al. 2019) across the land masses that encircle the Arctic Ocean. Glaciers, many of which have endured since the last Ice Age or longer, are now measurably smaller. Arctic weather is modulated by changes in the local climate, which is increasingly highly variable (NSIDC 2020). The interacting

[6] RAPID/MOCHA is a collaborative project of the US National Center for Atmospheric Research in partnership with the UK RAPID Program. https://climatedataguide.ucar.edu/climate-data/mocha-meridional-overturning-circulation-moc-and-heatflux-array

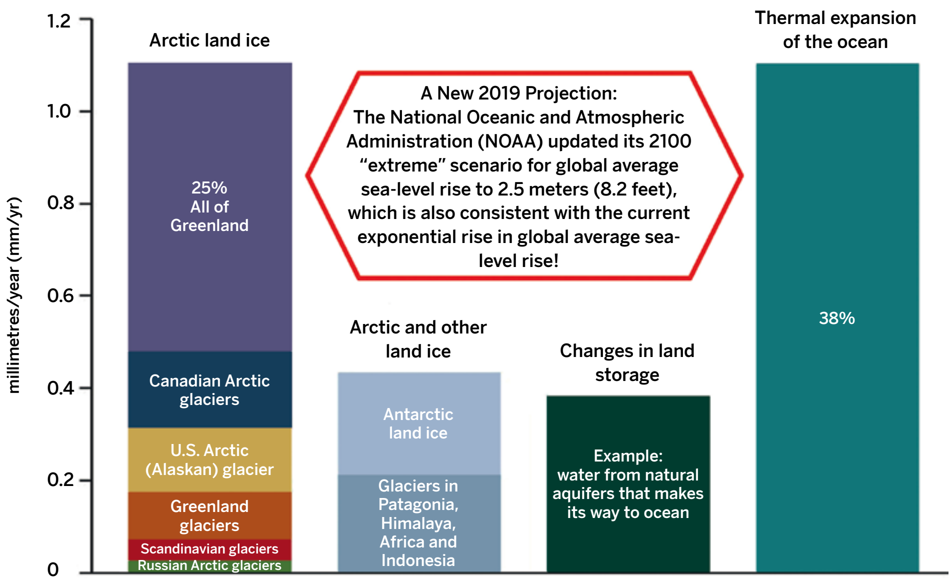


Figure 1.2: Comparison of global and Arctic sea-level rates, based on 2004-2010 sea-level data. Sea-level increases are dominated first by thermal expansion of warmer seawater and increasingly by the melting of land-based glaciers, leading to the multi-meter sea-level rise of this century. *Source:* Adapted from fig. 9.3 of the AMAP 2017 Report on Snow, Water, Ice and Permafrost in the Arctic.

factors of increased high-latitude ocean and atmospheric local temperatures affect local weather patterns and climate feedback, which changes the Arctic land ice regimes. In effect, Arctic climate change alters the local Arctic energy budget in ways that directly affect the melting rates of glacial land ice thus moving energy northward into the Arctic (Slater et al. 2019). Much of the Arctic's melting land ice and glaciers ultimately flows into the sea, adding volume to the world's oceans. Sea-level rise poses significant threats to human lives and infrastructure, especially in vulnerable and densely populated coastal areas. Currently, 75% of global sea-level rise is divided about equally between melted land-based ice in the Arctic and thermal expansion of global oceanic sea water (figure 1.2). Projections are that land-based glacial ice melting will dominate future sea level increases,[7] with Antarctica unpredictably contributing an increasingly greater share (Nowicki and Seroussi 2018).

[7] Researchers have concluded that the contribution to sea-level change from the loss of land ice will increase and will become the dominant source of sea-level rise over the course of the 21st century and beyond. See "A Research Program for Projecting Sea-Level Rise from Land-ice Loss," edited by Robert A. Bindschadler, Peter U. Clark, and David M. Holland. https://www.nsf.gov/geo/opp/usap_special_review/science_review/science_docs/nsf_sea-level_rpt.pdf

OCEAN–ATMOSPHERIC INTERACTIONS CONTROL NORTHERN HEMISPHERE WEATHER

Weather in the Northern Hemisphere is strongly influenced by changes in the dynamics of the Northern Hemisphere jet stream (called the tropospheric polar vortex), which in recent years has caused substantial shifts in cold air masses from the Arctic moving further south, and warmer air masses from the tropics moving further north. The jet stream exists all year and is increasingly responsible for creating and steering the high- and low-pressure systems that bring us our day-to-day weather: storms and blue skies, dry and wetter locations, warm and cold spells (Waugh, Sobel, and Polvani 2017). There is increasing evidence of an emerging change in the geographical patterns of jet stream circulation (figure 1.3), which is translating as an increased persistence of weather patterns resulting in an increase in the frequency and consequences of extreme climate events (Box et al. 2019).

Hurricane Sandy (2012), which substantially impacted New York City and the surrounding region, was caused by the jet stream being "stalled" over the city combined with

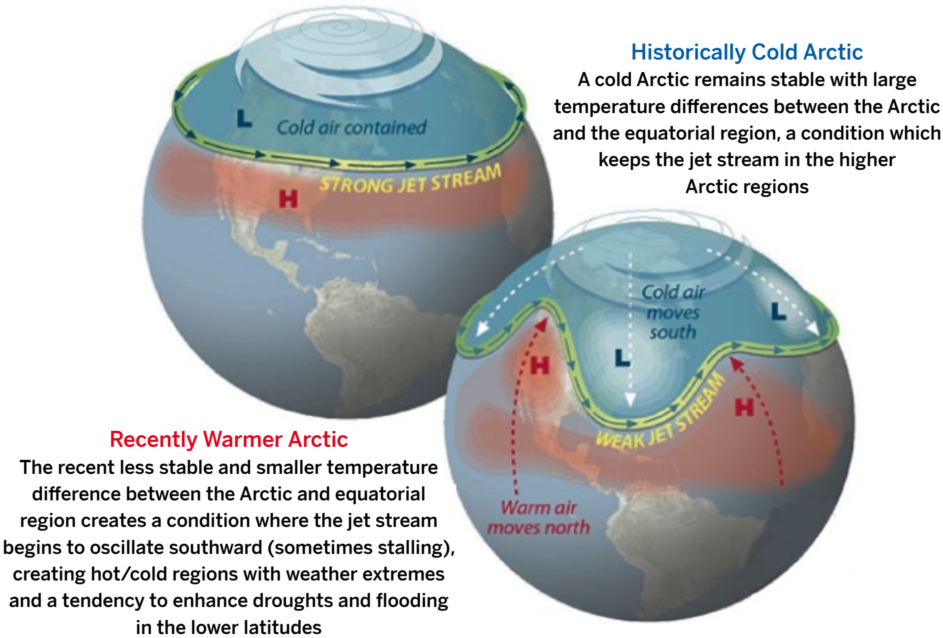


Figure 1.3: Weather patterns created by changes in the polar jet stream. Altered jet stream dynamics are changing the Northern Hemisphere's weather as it is oscillates more widely, alternately moving cold and warm air. *Source:* Adapted by RWC from Paul Horn, NOAA data and *Scientific American* graphics.

simultaneous interactions between it and, first, a classical Nor'easter over the North Atlantic Ocean, and, second, a strong hurricane arriving over a warmer southern Atlantic from the southeast. The resultant interaction was a stalled weather system that devastated the NYC region for days (NOAA 2012).

A warmer atmosphere means more water vapor in the atmosphere, which means individual storms will release more water/storm. For example, the United States has seen a 30% increase in such intense rainstorms (US National Climate Assessment 2014), which has increased flooding because of the inability of river systems to accommodate the higher volumes of rain water. Further, recent research findings show more frequent extremes across the globe, with storm events, previously occurring as 1-in-100-year events, now moving towards 1-in-20-year events (Lindsay 2016). These increases in extremes have profound consequences for societies' health and well-being (Hayes et al. 2018), and food and agricultural crop production (Zhao et al. 2017).

THE NEW ARCTIC: NAVIGATING THE REALITIES, POSSIBILITIES, AND CHALLENGES

The growing interest in the Arctic and the High North oceanic regions is bringing an influx of new people, cultures, ideas, and opportunities from all over the world, affecting many Arctic Indigenous cultures and communities. In the twenty-first century (Council on Foreign Relations 2014), many experts are projecting that climate change, technological advances, and rising global demand for resources will unlock the considerable economic potential of the Circumpolar North.

As projected, the melting of Arctic sea ice has already recorded unprecedented lows in recent years, which has prompted many nations, principally those with Arctic Ocean coastlines, the United States, Canada, Russia, Norway, and Denmark/Greenland, to reassess their commitments and interests in the icy reaches of the Arctic atop the globe. The debate is less over whether the region should be developed, but rather whether it can be done sustainably and peaceably (Wilson Center 2019).

The Arctic is emerging onto the world stage, and it is not yet settled whether businesses, governments, and other operators can fully manage the unique risks it poses. It is increasingly clear that the interconnectedness of the Arctic and global interactions are driven by key ocean processes in an Arctic inexorably nested in a global socio-economic and geopolitical framework, and, conversely, that the Arctic is increasingly affecting the global earth system. In effect, "the Arctic region has become a New Global Common."[8]

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[8] Cited as such in the introduction to the Walsh School of Foreign Service/Institute for the Study of Diplomacy report on "The New Arctic." See https://isd.georgetown.edu/research/global-commons/

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CHAPTER 2

THE ARCTIC AND CLIMATE CHANGE: A MAJOR SCIENTIFIC PROBLEM, AND A PLANETARY CHALLENGE

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THE ARCTIC AND GLOBAL WARMING

Anthropogenic greenhouse gas emissions are changing the planet, and in the Arctic this change is much more evident than anywhere else. Warming is in fact modifying completely the landscape and the geophysical basis of ecosystems. The very rapid decrease of sea-ice area is causing and will cause a dramatic and probably irreversible change—at least in a centennial scale—of the ecosystem, with the possible extinction of several sea-ice-dependent species.

Not only for this, the changes happening in the Arctic are impacting on the entire Earth system. A very evident observational impact is the disruption of the polar vortex that apparently led to winter cooling of parts of the Northern Hemisphere in the last decade. This phenomenon is related to the fast decrease in sea-ice area and thickness in all seasons. The strong southward meandering of the polar vortex that is frequently observed in winter today not only brings cold Arctic air southwards, but also warm meridional air masses towards the North Pole, impacting on the global climate.

A recent review paper (Cohen et al. 2020) has discussed this phenomenon, showing however that the observational data cannot be reproduced through Earth System Models by forcing them towards a strong decrease of sea-ice cover of the Arctic Ocean. Approaching the problem from a modelling side would therefore lead us to consider the observational winter cooling of part of the Northern hemisphere as the result of climate variability. This discrepancy will require new research, but the observational evidence shows that something is not yet understood in the relationship between the Arctic and the global climate. In another recent paper, Vaks et al. (2020) use paleo-climatological records and geological observations carried out in deep Siberian caves. They speculate that stable Siberian permafrost developed in relation with the establishment of permanent sea-ice cover on the Arctic Ocean about 0.4 million years ago. Previous periods of permafrost thawing took place in relation to periods without permanent sea-ice Arctic Ocean cover. A confirmation of these speculations might add another positive Arctic feedback on global warming, further reducing the 1.5°C and 2.0°C carbon budget ranges. It is worth adding that the possible disappearance of permanent Arctic sea ice under high emission scenarios has been anticipated to an average date of 2046 (2029-2066) by CMIP-6 models, with 50% of the models predicting summer sea-ice-free conditions between ~2030 and 2040 (Guarino et al. 2020).

Many other paleo-climatological observations of the last glacial period (approximately from 110,000 to 12,000 years before present), recorded in ice-cores drilled in the Greenland Plateau, show that twenty-five abrupt warming events happened during that period with changes of even more than 10°C of Greenland surface temperature over few decades. This was probably caused by changes in the Atlantic Ocean circulation with reductions of the Atlantic Meridional Overturn Circulation (AMOC)—the bi-polar seesaw—that affected the redistribution of heath from tropical areas. As a consequence of anthropogenic climate change the weakening and possible collapse of the AMOC is today widely debated, also in this case with divergent views within the scientific community (Caesar et al. 2018; Weijer et al. 2019).

The picture of the global significance of the Arctic is even clearer when we add sea-level rise to it. The IPCC Special Report on the Ocean and Cryosphere in a changing climate (IPCC 2019) shows that since the decade 2006-2015 the mass loss from the Greenland ice-sheet (and peripheral glaciers) became the larger mass contributor to sea level rise, passing all the remaining world glaciers. The previous IPCC Special Report on 1.5°C (IPCC 2018) indicated that an irreversible instability of the Greenland ice sheet may be triggered by global atmospheric warming between 1.5 and 2°C above preindustrial times, leading to a multi-meter sea level rise over a millennial time scale. Reductions of the AMOC—maybe triggered by Greenland melting—are also discussed by Clark et al. (2020) who link them to the rapid multi-meter sea-level rise that happened at the end of the last two glaciations as a result of greater Atlantic subsurface warming.

All this shows that the Arctic, with Greenland and the sea-ice covered Arctic Ocean, really acts as a complex Earth cooling system, and this has one clear consequence: changes in the Arctic cannot be treated any longer as a matter for the Arctic countries because its changes are impacting the entire planet, and because responsibility for those changes lies with all major emitters. The situation demands not just a pan-Arctic[1] approach but a much broader one.

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[1] It is worth mentioning the series of Pan-Arctic Integration Symposia since 2002, which led to the publication of three volumes, all edited by P. Wassmann, namely: 1) Structure and Function of Contemporary Food Webs on Arctic Shelves: a Pan-Arctic Comparison. Progress in Oceanography 71: 123-477 (2006); 2) Arctic Marine Ecosystems in an Era of Rapid Climate Change. Progress in Oceanography 90: 1- 131 (2011); 3) Overarching Perspectives of Contemporary and Future Ecosystems in the Arctic Ocean. Progress in Oceanography 135: 1-271 (2015). A fourth on "Towards a Unifying Pan-Arctic Perspective of the Contemporary and Future Arctic Ocean" is in preparation.

ARCTIC RESEARCH: A MULTILATERAL CHALLENGE

In September 2016, under the Obama administration and during the period of US chairmanship of the Arctic Council, the US called for a first Arctic Science Ministerial meeting (ASM1)[2] that was held in Washington DC at the White House (photo 2.1). Twenty-five Ministers or High representatives of Arctic and non-Arctic countries (including many non-Arctic European countries and the European Union, Asian countries such as China, Japan, Korea, India and Singapore, and even New Zealand) and representatives of the main Arctic Indigenous Peoples Organizations participated. The ASM1 marked a change in perspective, with the recognition that Arctic changes produce impacts on the entire planet, and that changes in the Arctic imply global responsibilities. The call for enhanced and broader international cooperation on Arctic research was taken-up by the European Commission (for the European Union), Germany and Finland that organized the 2nd Arctic Science Ministerial (ASM2)[3] two years later, in Berlin in October 2018 (photo 2.2).

The format of ASM2, with the involvement of Finland among the organizers during its turn to chair the Arctic Council (AC), created a functional connection with the AC efforts of promoting scientific cooperation that were marked during the same year by the entry into force of the AC Agreement on Enhancing International Arctic Scientific Coopera-

Photo 2.1: The First Arctic Science Ministerial discussion at the White House, September 28, 2016.

[2] See https://obamawhitehouse.archives.gov/the-press-office/2016/09/28/joint-statement-ministers

[3] See https://www.arcticscienceministerial.org/en/

Photo 2.2: German Chancellor Angela Merkel's welcome address to the Second Arctic Science Ministerial, Berlin, October 26, 2018.

tion.[4] This document—which is legally-binding for AC countries—has the purpose of "increasing effectiveness and efficiency in the development of scientific knowledge about the Arctic" through an agreement among the Parties in relation to intellectual property rights, entry and exit of persons, equipment and material for scientific research, facilitation of access to research infrastructures, facilities, and research areas, and access to data.

The broader scope of the two Arctic Science Ministerials is complemented and reinforced by the AC Agreement. It is evident that a great proportion of scientific activities in the Arctic are carried out in locations and territories of the eight Arctic countries. However, in Arctic observation and research we are using today a wealth of open access earth observation resources—such as those of the EU earth observation program Copernicus—together with open source modeling tools that allow us to produce a vast array of forecasting services. Several data and proxies of fundamental interest for the Arctic—take ocean mass movements for instance—are not even constrained within the Arctic Council parties' territories and waters. The Atlantification of the Arctic Ocean where it joins with the Barents Sea (Lind, Ingvaldsen, and Furevik 2018; Wassmann, Slagstad, and Ellingsen 2019), where food webs are changing rapidly, needs to be studied by following the movements of species—and the shift of warm and cold currents—across a great part of the Atlantic. Research centers and universities from all over the world carry on research

[4] See https://oaarchive.arctic-council.org/handle/11374/1916

Photo 2.3: The *Polarstern* trapped in ice during the MOSAiC expedition.

affecting the Arctic that is not limited to the Arctic as such. These activities are part of the scientific effort to understand key earth system processes and develop strategies for maintaining not only the Arctic, but the whole planet, within livable boundaries.

The first two ASMs have generated an important momentum in the deployment of Arctic research efforts, with large transnational actions promoted in particular by EU funding. The Germany-led MOSAiC expedition[5] —whose original idea precedes ASM1, was facilitated by the two Ministerials and by various cooperation agreements among funding agencies. Among the large EU-funded projects, top-down actions are ongoing and will receive further funding in support of the full development and deployment of an integrated Arctic observing system. These are based on architectures discussed within the SAON (Sustaining Arctic Observing Network) initiative,[6] jointly launched by the AC and the International Arctic Science Committee (IASC) and participated by the EU and others. However, it is also worth mentioning some important bottom-up initiatives that have received substantial EU funding, namely INTERACT[7] and ARICE.[8] These are two actions that support transnational access to circumpolar land-based research sta-

[5] See https://mosaic-expedition.org

[6] See https://www.arcticobserving.org

[7] See https://eu-interact.org

[8] See https://arice.eu

Photo 2.4: End of the Second Arctic Science Ministerial, Berlin, October 26, 2018. The EU, Germany and Finland hand over to Japan and Iceland, organizers of the Third Arctic Science Ministerial. *Left to right:* Carlos Moedas (Commissioner for Research, Science and Innovation of the European Commission), Mahiko Shibayama (Minister of Education, Culture, Sports, Science and Technology of Japan), Lilja Alfreðsdóttir (Minister of Education, Science and Culture of Iceland), Georg Shütte (Permanent State Secretary, Federal Ministry of Education and Research of the Federal Republic of Germany), and Sanni Grahn-Laasonen (Minister of Education of the Republic of Finland).

tions and infrastructures (INTERACT) and to an international research icebreaker fleet (ARICE), which are making the vision of an Arctic without barriers a reality.

Despite the low interest of the Trump administration in Arctic climate-change-related problems, scientific cooperation is still high with US scientific institutions. A recent first meeting of funding agencies as follow-up to the ASM2 agreements has shown growing international interest in broad multilateral cooperation.

In addition, the ASM2 Joint Statement of Ministers signed by all parties in Berlin[9] is probably one of the few examples of documents signed by the Trump administration that openly discusses the climate change challenge as the greatest challenge for the Arctic, where the benefits of a warming climate are overwhelmingly imbalanced by the risks at Arctic and global level. The Joint Statement spans three areas of scientific co-operation, namely:

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[9] See https://www.arcticscienceministerial.org/files/ASM2_Joint_Statement.pdf

1. Arctic observations and data
2. Understanding Arctic changes, their drivers and impacts at all scales
3. Assessing vulnerabilities and building resilience and adaptive capacity.

Moreover, the document calls for progress on making Arctic data free and open access and declares the intention of developing further the multi-lateral cooperation, including through a forum of research-funding agencies. Finally, it is ambitious in recognizing the role of Indigenous Peoples and local communities, and it presents international scientific cooperation as a means for maintaining the region as a safe and peaceful place, thereby giving value to its science-diplomacy dimension.

Having been in charge of preparing and negotiating this document on behalf of the European Commission, I can attest that it was not an easy job to achieve agreement on this text. Seven months of negotiations were necessary from the first draft to the signed document. What helped a lot was that the three organizers worked together on the importance of achieving a joint statement, focused on factual issues, and offering a win-win platform for all. Without disclosing elements of the Joint Statement negotiations that ought to remain under diplomatic discretion, it is possible to say that each country wished to represent in the document some specific interest emerging in particular from their own internal policy, such as the reconciliation process with Indigenous Peoples in Canada, or Russia's principle interest in Arctic resources exploitation. Only in limited cases did this lead to truly conflictual views. There was a genuine interest in achieving success, because there was a genuine interest in developing further cooperation. The success of the MOSAiC expedition is a tangible example of the interest in cooperation between Arctic and non-Arctic scientists and countries.

We live, unfortunately, in tough times for multilateralism, with a marked return of nationalism, and growing geopolitical and trade tensions. However, a little sign that broad multilateral cooperation is the only valid approach to Arctic research is also provided by the willingness of research ministries to continue the series of Arctic Science Ministerials with the on-going organization of the Third ASM in Japan at the end of 2020.[10] This will be a joint cooperation between the governments of Japan and Iceland, with the latter this time also holding the rotating chairmanship of the Arctic Council.

STEPS FORWARD

In order to further progress Arctic cooperation, future meetings for the implementation of the Arctic Council scientific cooperation agreement—together with future Arctic

[10] See asm3.org/home/

Science Ministerial meetings—have to be capable of jointly tackling the real hurdles to cooperation that still exist and hamper in particular the access to data and the access to research locations. These hurdles may sit at very different levels and may not always be possible to solve them through top-down policies.

In conclusion, my view is that, on the one hand, research related to changes in the Arctic requires not only a pan-Arctic approach, but an even broader one that can only be achieved by going far beyond the geographic dimension of the Arctic. However, on the other hand, it is equally evident that a growing interest in Arctic research is also triggered by interest in Arctic resources that are becoming more accessible because of climate change.

The 2018 legally binding Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean (CAOFA),[11] already ratified by a majority of its signatories, will be able to establish a moratorium until a Joint Program of Scientific Research and Monitoring (JPSRM) will have delivered sufficient results on the functioning of the Arctic Ocean ecosystem. The organization of the JPSRM—currently stirred by the Provisional Scientific Coordinating Group of the Preparatory Conference for CAOFA—will be another test of the interest of international scientific cooperation in the Arctic. Other Arctic protection agreements similar to CAOFA—entailing joint research programs—might be hopefully possible in other fields (such as sea-floor mining, deep drilling, etc.) that have the potential to cause major environmental damage in one of the few areas of the globe where pristine conditions still exist and should be maintained. The Arctic scientific community should make its voice heard.

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CHAPTER 3

COMPLEX COLLABORATION TOOLS FOR A SUSTAINABLE NEW ARCTIC

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In the fall of 1978, Francis Fay, a scientific authority on walruses, received a call from Alex Akeya, an Indigenous hunter on St. Lawrence Island in the Northern Bering Sea. Alex reported thousands of dead walruses on the island and coastlines of the Bering Strait and asked for help understanding the cause. One of the authors of this chapter (Kelly) was pressed into service circumnavigating the island and performing a great many backbreaking necropsies (postmortem examinations to determine the causes of death). The forensics were quite straight forward; the walruses had come ashore in unusually large numbers, they were abnormally thin, and almost all had been crushed when large numbers of animals stampeded, simultaneously trying to flee the beach (Fay and Kelly 1980).

Less straightforward was the media coverage of the events. Based strictly on the large number of carcasses, some resource managers reported, without evidence, that the mortality resulted from wanton slaughter by Indigenous hunters seeking ivory. Journalists spread those assertions widely before the first necropsy began. Fay and Kelly depended on Akeya's navigational and knife-sharpening skills and his good humor as they documented the extent and causes of the mortality. What they were not able to resolve was why the walruses in 1978 were in such poor condition that they succumbed to stampedes. Elders on the island helped put the event in historical context with their detailed accounts of previous mass mortalities in the region.

Collaborating with Indigenous hunters came easily to Fay who started learning from the hunters of St. Lawrence Island in 1950. Other scientists in that era also collaborated extensively and productively with Indigenous hunters, but incidents like the managers' false narrative about the hunter's role in the walrus mortality event contributed to break downs in trust and considerable tension. Increasingly, however, Indigenous Peoples are further asserting their rights and interests in processes of natural resource management, and there are signs that trust is being re-established with the science community.

Photo 3.1: Mass Mortality of Pacific walruses. Thousands of walruses died on the islands and coastlines of the Bering Strait in autumn 1978.

While these advances are promising, the rapid and extreme changes in Arctic Ocean and other environments create an urgent need to muster the knowledge and skills of scientists, Indigenous experts, and policy makers to collaborate toward a sustainable socio-ecological system in the Arctic. How, exactly, to engineer a successful collaboration of such diverse parties is not obvious. We propose, however, that a sustainable Arctic will depend as much on such an intricate collaboration as on effective observing systems and climate models. This chapter will, therefore, explore the need and potential for tools to facilitate such a grand collaboration.

SHARED FRAMEWORK: A NECESSARY TOOL FOR COMPLEX COLLABORATION

The tragedy of the commons is set to play out in the Arctic with global ramifications, and we know that technologies and scientific theories have seldom been sufficient in solving other instances of self-interested parties working against the common good. Moreover, we know that change in the Arctic affects—and is affected by—people living in the region and beyond. Thus, impactful research and coherent responses need to be informed by Arctic residents—including those who have occupied the region for hundreds and thousands of years—as well as scientists from diverse disciplines and decision makers from local to international levels of government.

One may argue that including such diverse inputs will result in too many cooks in the Arctic kitchen. Indeed, non-linear increases in complexity can be expected in engineering such broad collaborations. Yet, we argue, that we can and must create new tools to harness the diversity, however complex. The expediency of simply reducing the diversity of voices would come at too high an information cost and likely leave us in a new Arctic that is neither peaceful nor sustainable. We propose building a shared conceptual model of the Arctic socio-ecological system to harness the knowledge and shared values of the many Arctic players–a framework for managing a complex collaboration. A co-produced and evolving conceptual framework of a sustainable Arctic system would keep values at the forefront as individuals contribute observations and other input, have educational value, and provoke on-going cross-sector discussions of who and what should be considered for research needed to inform decisions.

An effective conceptual framework for complex collaboration will have to be co-produced by a diverse team with a clear sense of shared values and an appreciation of complex systems and systems thinking. Here, we can only elaborate on the essential need for such a framework and suggest some minimal design needs.

FACILITATION THROUGH SHARED VALUES

Individuals unite into groups around shared values. For example, scientists value expanding the body of knowledge, Inuit value social cohesion including making decisions through discussion and consensus, and conservationists identify with values such as maintaining biodiversity. In multiple fora concerning the future of the Arctic, we observe that diverse participants express concern about the state of the Arctic their grandchildren will inherit. We suggest that Arctic scientists, Indigenous Peoples, and policy makers already share a desire for a sustainable socio-ecological system and that shared values could serve as the starting point for development of the framework and a frequent touchstone in its subsequent evolution.

Early attention to—and resources for—co-defining a unified vision and guiding principles (for example, trust, fairness, and respect) will be key to their effectiveness. An especially large hurdle will be the reallocation of time and effort required of participants. Some of the time currently spent in scientific, Indigenous, and policy convenings or activities will need to be given over to the larger collaboration. Motivating such reallocations will require convincing potential participants that realizing their value of a sustainable Arctic will depend on the concerted efforts of the diverse coalition. Recognizing and addressing capacity needs of certain participants will also be necessary. For example, Indigenous participants may have less access to travel funds, while the pace of their work may limit participation of policy makers in multi-day workshops.

Even when people come together around common values, sustaining group cohesion depends on trusting relationships. Such relationship building is important to the persistence and effectiveness of any collaboration and would be especially important in the case of a collaboration spanning continents and worldviews. Intentional support for connections built through shared experiences and informal conversations would be essential. An emphasis on human well-being (e.g., food security and health) would also support group cohesion and help reinforce the human interests inherent in sustaining the Arctic socio-ecological system.

EMBRACING COMPLEXITY

A framework, intended to connect those making observations and predictions with those setting policies and those experiencing the impacts of Arctic environmental change will have to span multiple languages, worldviews, and political systems. It would be a tremendously complex undertaking but as vital as engineering climate models—comprising over a million lines of code—or observational satellites—arrayed with highly advanced sensors. Yet, much of the value of the knowledge gained from sophisticated observations and earth system models is lost because of ineffective assimilation into policy decisions. Bringing people of different cultures, countries, and disciplines together is expensive, time consuming, and organizationally challenging, but vital if we are to harness what we know in steering a course to a sustainable new Arctic.

Building a shared framework for informing Arctic policy might start with considering how other complex systems have been engineered and examining examples of successful complex collaborations to ask what components were key. We might start by asking Indigenous leaders how they orchestrate collaboration of multiple tribes as in, for example, the Inuit Circumpolar Council? Climate modelers surely have lessons to share from bringing together experts from diverse fields to construct earth system models (e.g., the Community Earth System Model). Similarly, the Sustaining Arctic Observing Network spans all of the Arctic countries to coordinate scientific and Indigenous observations of the Arctic Ocean, lands, and cryosphere. No doubt, there also are lessons to be learned from many complex collaborations outside of the Arctic, but we start with Arctic organizations as they would be prime candidates to involve in building our framework. Querying them about lessons from their collaborations would both inform the building of the broader collaboration while, at the same time, inform them about the framework's potential to extend the impact of the knowledge they have produced.

Examples of successful collaborations of the sort we envision exist in multiple spheres. Trans-national examples include collaboration in fisheries management and research by Norway, Russia, and the International Council for the Exploration of the Sea. While widely seen as a successful bilateral collaboration, Wassmann—in a panel on Implications of Changing Marine Ecosystems at the Arctic Futures 2050 conference—suggested that the collaboration needs to be broadened to include other Arctic nations.

Photo 3.2: Bowhead whale harvest. Inupiaq hunters butcher a whale on the ice in Alaska.

The benefits of cross-cultural collaboration were evident in Canada's recent establishment of a national marine conservation area in the Canadian Arctic Archipelago. The Government of Canada, the Qikiqtani Inuit Association, and the Government of Nunavut relied on Inuit and conservation values as well as Inuit and scientific knowledge to determine effective boundaries and management of the protected area. Those involved in establishing the preserve attest that the negotiations were not easy, but they were facilitated by increasing appreciation of the importance of combining multiple perspectives.

The movement toward more diverse voices informing policy also is evident in the evolution of the management and research of bowhead whales in Alaska. Over a contentious four decades, the US government and Inupiat whalers progressed from near total disagreement on the science and, certainly, on the prudent management of the whale population to a strong collaboration. It took near saintly patience on the part of an Indigenous and a scientific leader to keep the various voices at the table, and now the whalers, researchers, and federal managers work very effectively to co-manage a healthy population and regular harvests.

Successful collaboration on fisheries management between Norway and Russia, on marine conservation between the Inuit and Canadian governments, and on whale management between the Inupiat and the US Government are encouraging, but we do not want to minimize the challenges especially where the need is to move beyond bilateral collaboration. After decades of missed opportunities to cooperatively manage Pacific walrus populations, the United States and Russia began substantial research collaborations and coordinated management in 1972, but the coordination retains deficiencies, and inclusion of Indigenous hunters in that collaboration remains inadequate in the United States and Russia (Fay et al. 1997; Kryukova 2019).

EMPLOYING A SYSTEMS LEVEL APPROACH

By its very nature, the challenges of Arctic environmental change cannot be adequately addressed from a single perspective. Just as medical research is hampered by inadequate exchanges between clinical researchers, clinicians, and patients (Ioannidis 2016), environmental research will benefit from co-production by scientists, policy makers, and those most impacted by the changes.

In the past few decades, researchers have substantially advanced understanding of the interactions between the physical, living, and social elements of the Arctic, i.e., a system understanding that has increased predictive skills. The complexity of the unprecedented changes taking place in the Arctic calls for building on those advances and expanding to a systems level understanding of Arctic change shared across disciplines, cultures, and governments. A systems approach to a co-produced conceptual model will be appropriate to the complexity and ongoing evolution of the Arctic socio-ecological system. Many scientists are familiar with the approach, and it reflects the holistic perspective of many local peoples.

Photo 3.3: A panel at the Arctic Futures 2050 Conference (2019). Under discussion was the collaboration of scientists, Inuit leaders, and government officials in establishing a marine conservation area in Arctic Canada.

Inuit view themselves as inseparable from the Arctic environment which is likened to "a puzzle, with all pieces having a place and all pieces necessary to make up the entire picture. These pieces include Inuit languages, retention of Indigenous knowledge, animals, oceans, rivers, etc." (Inuit Circumpolar Council—Alaska 2015). Arctic scientists have similarly referred to a "puzzle" when considering "the most urgent next steps towards a broader ecosystem understanding" (Wiese et al. 2015). In the last International Polar Year, an even broader community of Arctic scholars endeavored—with mixed results—to bring together scientists and Indigenous experts to "synthesize a plethora of individual research findings and scientific products into a system-wide understanding of Arctic change." (Krupnik et al. 2011). Understanding the Arctic as a complex-adaptive system has broad appeal, and marine ecologists, in particular, have embraced systems thinking in their research, and it is consistent with the holistic perspective of the Inuit and other Arctic residents. Nonetheless, for some participants, at least, learning to think in systems terms will add to the complexity of the collaboration.

BENEFITS AND CHALLENGES

Existing instruments for integrating a diversity of perspectives into policy may or may not have been adequate when there was regularity to the seasonal cycle of sea ice, when sea ice supported feeding adult walruses and their nursing calves. But, in this era of unprecedented change in the Arctic, we argue that there is an urgency to creating new instruments for combining the knowledge and perspectives of Arctic residents, scientists, developers, and policy makers. A common conceptual framework, such as we propose, could improve our ability to ask the right questions and integrate the answers from diverse respondents. Thus, a policy maker might be interested in scientific questions about future rates of ice loss. Of course, the policy makers also will want to hear from business leaders about the opportunities occasioned by diminishing sea ice. It quickly becomes apparent that the new Arctic will emerge not from one or even a few decisions, but as a consequence of many individual decisions made by local communities, governments, developers, and researchers. If the sum of those individual decisions is to yield a peaceful and sustainable future, it will be necessary (but not sufficient) to create some coherence to the questions and answers.

The climate modeling community appreciates the urgency of accurately predicting environmental change, and they draw on a vast array of experts to mathematically connect first principles in ever more powerful models. Yet, at least some climate modelers acknowledge that the models would be further improved by input from experts who do not write code or express their knowledge and concerns quantitatively. A framework for more diverse and complex collaborations would enrich inputs to models, help focus research responses to societal needs, and have educational value. By its nature, such a collaboration would require hearing diverse perspectives and gaining greater appreciation for the knowledge of scientific, Indigenous, and other experts.

Photo 3.4: Russia and the United States have made strides in cooperative research and management of the Pacific walrus population, but inclusion of Indigenous hunters remains inadequate.

In addition to its complexity, such collaboration will be challenged by its expense in time and resources as well as by deficits in scientific and Indigenous knowledge literacy. These are difficult but manageable challenges. Reallocation of time and resources will be mandated by environmental change, and proactive investment in complex collaborations will be less expensive than merely reactive investments. At the same time, the collaboration would provide fora for increasing understanding and the capacity to respond to environmental change in the Arctic. Scientists would have the opportunity to improve science literacy by making what they know accessible to diverse audiences, and Indigenous Peoples would be able to bring their knowledge to people with little or no exposure to it. Ideally, all could benefit from what Albert Marshall, an Indigenous elder in Canada, calls "two-eyed seeing…learning to see from one eye with the strengths of Indigenous knowledges and ways of knowing and from the other eye with the strengths of Western knowledges and ways of knowing…and learning to use both these eyes together."

Twenty years after the mass mortality of walruses in the Bering Strait region, collaboration with Russian and US government scientists and Inupiat hunters revealed further insights into the causes of the mortality. Ship-based surveys of Pacific walruses in the late 1990s showed that much of the summer ice in the Chukchi Sea had retreated north of the continental shelf. Thus, the sea ice platform for nursing calves was decoupled from water shallow enough for their mothers to obtain their benthic prey. At the time, we could only speculate about the relationship between the walruses' nursing and foraging habitats in 1978, but subsequent collaborations among historians and sea ice experts provided evidence that the ice indeed had been north of the continental shelf for much of the summer in 1978 (Walsh et al. 2019). The combined insights of Indigenous hunters, biologists, sea ice experts, and historians were necessary to understand how the changing Arctic was impacting walruses, an important resource for people of the region. We believe the case illustrates that there are only "too many cooks" in the Arctic if their collaborations toward a sustainable new Arctic are insufficiently coordinated.

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CHAPTER 4

MOVING FORWARD ON ARCTIC OCEAN GOVERNANCE

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INTRODUCTION

The Arctic Ocean has experienced dramatic change over the past decade. A warming climate has driven much of that change, drawing heightened attention to the environmental concerns and economic opportunities that have already arisen in the Arctic and to the other developments that are surely coming. Geopolitical tensions—including those involving China, Russia, and the United States—have spilled into the Arctic as well.

The states and peoples of the Arctic have struggled to keep pace with all this, to cope with the profoundly changing climate, and to manage the increasing human activity. The Arctic Council has emerged as the major—but not the only—international forum for pursuing cooperation on circumpolar issues. The Council has evolved since its inception in 1996. But will the Council as currently structured, and other initiatives to strengthen Arctic governance, prove adequate to address future needs and circumstances? The Arctic Ocean will likely require something more. Where do we go from here if we hope to strengthen Arctic Ocean governance?

RECENT DEVELOPMENTS

Until recently, the Arctic Ocean did not require extensive international cooperation, as year-round sea ice coverage—and the absence of modern technology to allow people to operate in its harsh conditions—made large-scale human activities in much of the area difficult if not impossible. But times have changed.

In 2019 the Intergovernmental Panel on Climate Change issued a Special Report confirming that the Arctic is warming at more than twice the global average (IPCC 2019). In the Arctic Ocean, average sea ice cover and volume have shrunk in every month of the year. Coastlines previously protected by frozen shorelines year-round are eroding as the

Photo 4.1: Arctic Council Ministerial Meeting in Iqalutt, Canada (2015).

sea ice melts. Positive feedback loops are accelerating change as the darkening surfaces absorb more heat, which leads to further melting, and as the thawing permafrost releases stored carbon and methane.

Large portions of the Arctic Ocean are now ice-free for several months each year. Scientists predict that the entire Arctic Ocean will be ice-free during the summer before the middle of this century. These same phenomena are, of course, also making possible new opportunities. As foreseen in the 2009 Arctic Marine Shipping Assessment, we are already witnessing more Arctic shipping—related to both transport and tourism—a trend that is almost certain to continue. The warming Arctic Ocean may also make possible significant new offshore hydrocarbon development and potential new fisheries.

To govern the changing Arctic Ocean, states have responded in a number of ways. They have primarily acted through the Arctic Council, which rightly bills itself as the "leading intergovernmental forum promoting cooperation…on common Arctic issues." The Council initially made its name through its analyses and assessments, such as the first Arctic Climate Impact Assessment (ACIA 2005) and the Arctic Council Arctic Marine Shipping Assessment (2009), noted above. Over time, the body has played a greater role in policy making, including with respect to Arctic Ocean issues. The question left unanswered is whether the Arctic Council—a flexible forum based on a non-binding political statement rather than a treaty, with no ability to bind its members to any decisions, and with haphazard funding arrangements—provides an effective international regime managing the increasing activities in the Arctic Ocean.

The eight member States of the Arctic Council have found one way to achieve binding results through the Council. Three times in the past decade they met under the auspices of the Council for the purpose of negotiating treaties. Each of the resulting agreements—on search and rescue, on marine oil pollution, and on scientific cooperation—relate largely if not exclusively to the Arctic Ocean. In other words, the Arctic States managed in these instances to work around the limitations of the Arctic Council to strengthen Arctic Ocean governance.

States have also strengthened governance through means unrelated to the Arctic Council. For example, states turned to the International Maritime Organization (IMO) to develop the Polar Code, which will improve the safety and environmental security of vessels operating in the Arctic and Antarctic regions. Nine states and the European Union concluded the 2018 Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean. This treaty, negotiated outside of any international body, commits its parties, *inter alia*, not to authorize commercial fishing in the large high seas area in the Central Arctic Ocean for at least 16 years following its entry into force.

These efforts to strengthen governance of the Arctic Ocean have largely occurred at a time of serious friction between Russia and other Arctic States. When it came to the Arctic, the states seemed willing—until recently—to set aside their differences in favor of working cooperatively to address common concerns. It appeared as though the era of strengthening Arctic Ocean governance would continue, possibly even accelerate. The outlook now is not so rosy.

CURRENT CIRCUMSTANCES

In May 2019, US Secretary of State Pompeo traveled to Finland to participate in the Arctic Council Ministerial Meeting in Rovaniemi. Before reaching Rovaniemi, he stopped in Helsinki to offer his views about the Arctic region.

In his speech, Secretary Pompeo stated that the Arctic "has become an arena for power and competition…complete with new threats to the Arctic and its real estate, and to all of our interests in that region." He raised particular concerns about the "aggressive behavior" of China in the Arctic. He also sharply criticized Russia, similarly pointing to a "pattern of aggressive Russian behavior here in the Arctic. Russia is already leaving snow prints in the form of army boots." For good measure, he also noted the "long-contested feud" between the United States and Canada concerning the rights of vessels to transit the Northwest Passage (Pompeo 2019). If Secretary Pompeo hoped to unify the Arctic States in the face of new threats, he did not succeed. The following day, at the Ministerial Meeting itself, the Arctic Council failed—for the first time—to reach agreement on a Declaration to capture the accomplishments of the Finnish chairmanship and to provide a mandate for the new Icelandic chairmanship. Most accounts laid the blame for this failure at the feet of the United States, for failing to accept language in the Declaration concerning climate change in the Arctic that all other Arctic Council members deemed essential. The lack of an agreed Ministerial Declaration in 2019 constitutes only one of the recent disappointments of the Arctic Council. At least one other of those disappointments relates to governance of the Arctic Ocean.

The Arctic Council Force on Arctic Marine Cooperation (TFAMC), created in 2015, had an initial mission "to assess future needs for a regional seas program or other mechanism" for the Arctic. Following two years of work, the TFAMC identified nine "unmet needs"—obstacles to better cooperation on Arctic Ocean issues. The Arctic Council could, in the judgment of the TFAMC, meet some of those needs by enhancing its working procedures and internal coordination. But the Council could only meet the full range of those needs by establishing a new body within the Arctic Council framework dedicated to Arctic Ocean issues (Arctic Council 2017a).

When former US Secretary of State Tillerson presided over the 2017 Ministerial Meeting in Fairbanks, the Council "recognize[d] the increasing need for regional cooperation to promote the conservation and sustainable use of the Arctic marine environment" and gave the TFAMC a new mandate to present "terms of reference for a possible new subsidiary body, and recommendations for complementary enhancements to existing Arctic Council mechanisms, for consideration by Ministers in 2019." (Arctic Council 2017b). The 2017 Ministerial Meeting may have represented the high-water mark for progress on this matter, at least for now. Over the ensuing two years, the TFAMC did not fulfill its mandate to present terms of reference for a new Arctic Council subsidiary body. Those concerned with strengthening Arctic Ocean governance can nevertheless find one bright spot from the 2019 Ministerial Meeting. In lieu of an agreed Declaration, Finland's Minister of Foreign Affairs issued a non-consensual Chair's Statement that included a commitment to "establish a SAO based mechanism to coordinate marine issues in the Arctic Council." The Arctic Council now needs to figure out what this "SAO based mechanism" will really do, and how it will operate.

Outside the Arctic Council, prospects for continued cooperation may be brighter. In 2018 the IMO, following up on the Polar Code, approved a joint proposal by Russia and the United States to create shipping lanes through the Bering Strait. Although the traffic separation scheme is voluntary, one would expect vessels transiting the Strait (in increasing numbers) to follow the new "rules of the road," thereby reducing the risk of an accident. The IMO is also making progress toward a possible phase-out or ban on the use and carriage of heavy fuel oil in the Arctic Ocean. The Central Arctic Ocean Fisheries Agreement will likely enter into force in the near future. The signatories have already met on multiple occasions to prepare for this and have already agreed in principle on initial steps to implement the scientific aspects of the accord.

Finally, a number of developments at the global level may have consequences for Arctic Ocean governance. The United Nations has declared 2021–2030 as a "Decade on Marine Science for Sustainable Development" and selected the Arctic Ocean as one of the regional focal points. UN Members are also negotiating a new binding agreement relating to the "conservation and sustainable use of biodiversity in marine areas beyond national jurisdiction." This treaty could affect the governance of those portions of the Arctic Ocean beyond the jurisdiction of coastal States, including the large high seas area in the Central Arctic Ocean. With many of the provisions of the envisioned agreement still unresolved, however, its ultimate effects on ocean governance—in the Arctic and elsewhere—remain difficult to assess.

NEED FOR A STRONGER GOVERNANCE ARCHITECTURE

The present moment seems an odd one in which to call for new and stronger international architecture for governing the Arctic Ocean. The great powers—China, Russia, and the United States—seem more intent on competing with each other than in cooperating in the Arctic—or most anywhere else. The media tend to focus on the differences among these great powers and, in doing so, may actually exacerbate the challenges of today's diplomatic environment.

That said, the Arctic interests of the great powers, particularly Russia and the United States, remain similar. Both claim to desire a peaceful Arctic, one that is stable and rules-based. Both claim to want to develop the Arctic in an environmentally sustainable manner. Both claim to respect the rights and interests of Arctic Indigenous Peoples. Both seek to promote scientific understanding of the Arctic. It is worth recalling that Russia and the United States jointly led the negotiations on all three of the binding agreements produced under Arctic Council auspices.[1] Two of those negotiations took place during ongoing hostilities in Crimea and Syria. Clearly, Russia and the United States chose to compartmentalize—to exercise joint leadership in the Arctic notwithstanding serious divergences in their interests and policies elsewhere.

[1] In the case of one of those agreements (on marine oil pollution), Norway also served as a co-leader of the negotiations.

The prospects for continued compartmentalization, for keeping the Arctic collaborative rather than completive and antagonistic, may look poor at present. But the Arctic as an unlikely region for statesmanship has surprised people before. One need only recall how, thirty years ago, the Arctic emerged from decades in which Russia and the West viewed it largely as a Cold War theater, to become an unexpected model of far-sighted international collaboration. With the hope that cooler heads will prevail—even as the Arctic warms, or possibly in part because the Arctic is warming—some suggestions for strengthening the international architecture for governing human activities in the Arctic Ocean may prove helpful even now.

One place to start would be with the unmet needs that the TFAMC identified in 2017. Of those unmet needs, four would most benefit from new or strengthened international governance arrangements:

1. Regional cooperation in the development and regular assessment of ecological quality indicators and objectives.
2. Regional assessment, monitoring, and accountability.
3. Integration across sectors and jurisdictional boundaries.
4. Regional cooperation on area-based stewardship.

The Arctic Council contributes—and could contribute more—to meeting some of these needs, particularly items 1 and 2 above. In some cases, the Council also engages with other international bodies—and could do so more—in efforts to address those needs. For example, the Council is collaborating with two international marine science organizations toward an Integrated Ecosystem Assessment of the Central Arctic Ocean. The information that the Assessment will contain should prove useful in considering ways to manage the increasing human activity in this part of the Arctic Ocean in years to come.

Items 3 and 4 speak directly to the need to manage those human activities. Despite the recent increase in such activities, the Arctic Ocean remains relatively little used compared to other parts of the world's oceans. Thus, the states concerned have the rare chance to act before the onset of large-scale commercial undertakings. Just as the Central Arctic Ocean Fisheries Agreement has put in place measures to address high seas fisheries before they commence, so too can the states concerned put in place approaches to ensure that other commercial activities develop sustainably. They can, to borrow the words of items 3 and 4, act now to integrate management actions across sectors and jurisdictional boundaries and, more generally, become true stewards of the Arctic Ocean through regional cooperation.

With sufficient political will, the SAO based mechanism that the Arctic Council is launching may meet these needs in part. The Council long ago embraced the "ecosystem

Photo 4.2: A container ship approaches the port of Anadyr, Russia. Arctic shipping is increasing, and with it the need for effective shipping regulation.

approach" to marine management (sometimes shortened to "ecosystem based management" or EBM). The pursuit of effective EBM in most places in the world, including the Arctic, remains just that—a pursuit. Unlike most other parts of the world's ocean, however, relatively few States surround the Arctic Ocean, and all of them rank high on a world scale in terms of capacity to implement EBM.

However, even if the Arctic Council uses the SAO based mechanism robustly, and even if it undertakes the other *enhancements* in its working methods that the TFAMC recommended, it will still remain saddled with its innate limitations. The Arctic Council, without legal personality, without dedicated and predictable funding, and without the ability to bind its members to decisions, cannot on its own serve as the international regime through which states can actually achieve effective EBM throughout the Arctic Ocean. To overcome these limitations, some have suggested that the Arctic Council should be re-established—transformed into another type of body, with a new structure and a new mandate set forth in a new binding international agreement. They point to other international entities that have undergone such transformations successfully, such as the Organization for Security and Co-operation in Europe. Others have suggested that the Arctic Council could remain essentially as it is currently configured, but that it should build more collaborative links with other international bodies such that decisions taken by the Council could be made binding and implemented through those other bodies, including the IMO and the International Seabed Authority.

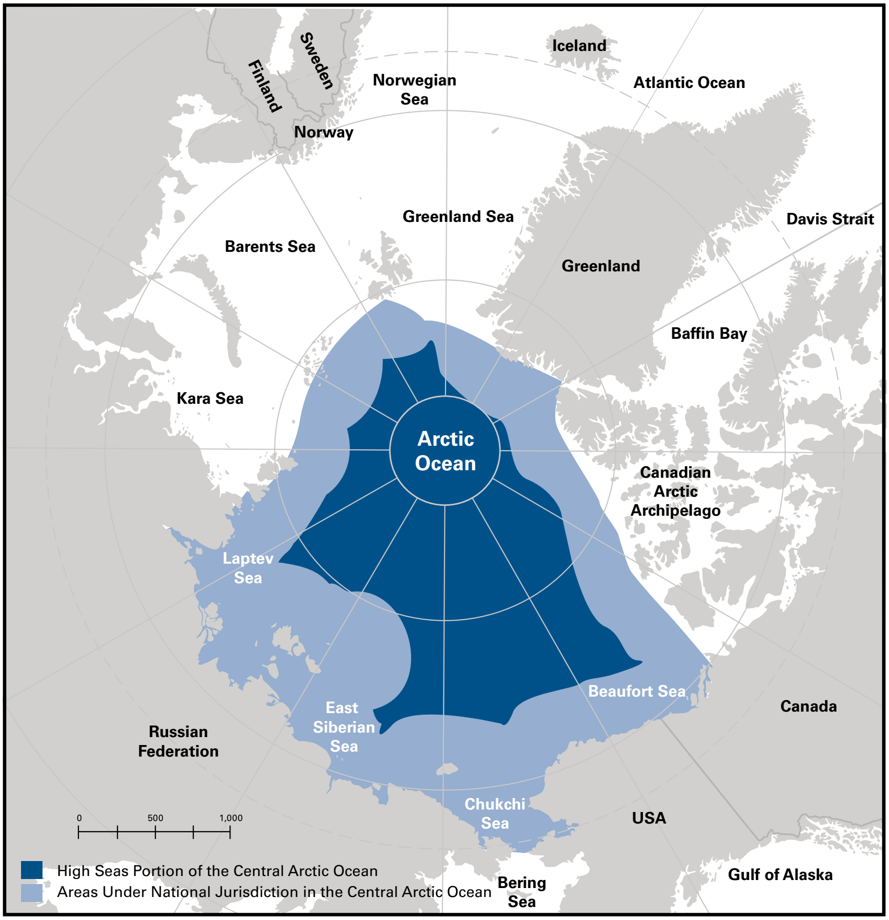
Either of those approaches would improve the existing governance regime. A third approach also exists that would entail leaving the Arctic Council more or less unchanged, thereby allowing it to continue the good work that it currently does, while also building new regional bodies for the Arctic Ocean (or at least for the Central Arctic Ocean) that could perform two functions that the Arctic Council does not and cannot perform, as discussed below.

A NEW MARINE SCIENCE BODY FOR THE CENTRAL ARCTIC OCEAN

Within the Arctic Ocean, the Central Arctic Ocean as depicted below—both the light and dark shaded areas—is certainly the least understood part. Indeed it is probably the least understood part of any of the world's oceans. In order to manage increasing human activity there, we simply need a lot more information (map 4.1). No existing international body can fill this need adequately. The Arctic Council does not undertake marine scientific research on its own. Two marine science organizations—ICES and PICES—have recently devoted some of their attention to the Central Arctic Ocean, but their geographic mandates relate primarily if not exclusively to the North Atlantic and North Pacific, respectively.[2]

Why not create a new marine science organization dedicated solely to the Central Arctic Ocean? Like ICES and PICES, such an organization would need to be established by a treaty, have a clear mandate, and receive assured funding. Difficult questions would necessarily arise in creating such an organization, including its precise geographic scope, its membership, participation by Arctic Indigenous Peoples, and its relationship to other international bodies, etc. Answers to each of those questions lie within reach, however, provided once again that the political will to find them exists. Those presently involved with ICES and PICES, and possibly with the Arctic Council, may fear that a new marine science organization of this sort would require adjustments to the mandates and the work of these existing international bodies, adjustments that they would prefer not to make. Change is often difficult. It no doubt took considerable time and persuasion to build support for the establishment of ICES, PICES, and the Arctic Council too. Eventually, enough people saw that each of these entities would fill an obvious need, making

[2] The treaties creating the International Council for the Exploration of the Sea (ICES) and the North Pacific Marine Science Organization (PICES) make clear that their primary areas of responsibility lie outside the Arctic. The 1964 ICES Convention provides that it "shall be concerned with the Atlantic Ocean and its adjacent seas and primarily concerned with the North Atlantic." The 1990 PICES Convention limits its geographic mandate to the "temperate and sub-Arctic region of the North Pacific Ocean and its adjacent seas, especially northward from 30 degrees North Latitude."



Map 4.1: The Central Arctic Ocean.

possible their creation. Perhaps something similar will happen with respect to the suggested marine science organization for the Central Arctic Ocean.

The current political climate may not provide fertile ground in which the seeds of this suggestion can grow. On the other hand, leaders may find the idea attractive precisely because it provides a non-threatening and inexpensive way to demonstrate their ability to rise above the fray and take far-sighted action for the common good.

A MANAGEMENT BODY FOR THE CENTRAL ARCTIC OCEAN

Over the longer term, such leaders may also come to see the benefits of an additional mechanism for the Arctic Ocean, or at least for the Central Arctic Ocean, within which to negotiate and adopt measures for managing human activities there.[3] Those measures would, in principle, be based on the scientific information and advice generated by the suggested new marine science organization, among other sources. The management body could fill the needs related to EBM reflected in items 3 and 4 discussed above. It might be possible to house this body within the framework of the Arctic Council. As noted, though, the current configuration of the Arctic Council does not allow it to perform the required functions. States concerned would need to reconstitute the Arctic Council, or parts of it, for this purpose and imbue the new entity with appropriate authority.

The other approach would be to establish the management body outside the Arctic Council framework. Most States in the Arctic have experience with such entities in areas near to the Arctic, including the Baltic Marine Environment Commission (generally known as HELCOM) and the OSPAR Commission, the marine management organization for the North-East Atlantic.

Once again, the States concerned would need to confront and resolve issues relating to the nature and mandate of the new organization. These issues would likely prove more sensitive than those attending the establishment of a science body, inasmuch as management decisions would affect commercial activities of direct economic interest to the states involved, including in ocean areas within the jurisdiction of Arctic coastal states. Still, negotiators have found ways to solve such problems elsewhere.

CONCLUDING REMARKS

These suggestions for strengthening Arctic Ocean governance may strike some as wishful thinking. Admittedly, the prospect that the states concerned with the Arctic Ocean will, in the immediate term, set aside their differences to take up such suggestions seems remote. Circumstances change, however. Windows close and windows open, often in unpredictable ways. Today's era of great power competition in the Arctic—if that is indeed today's reality—may give way to a renewed period of international cooperation and collaboration for the Arctic. Or perhaps we are still in the cooperative period that began in the 1990s, overlain by heated rhetoric of a passing nature. Time will tell. The outcome of the 2020 US election bodes well, at least insofar as the incoming US administration will take more seriously the need to combat climate change in the Arctic and elsewhere. In the meantime, the unmet needs of the Arctic Ocean continue to exist.

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[3] That is, activities other than commercial fishing, which is already the subject of the Central Arctic Ocean Fisheries Agreement.

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CHAPTER 5

THE ROLE OF UNIVERSITIES INSIDE AND FOR THE ARCTIC

ANNE HUSEBEKK AND KENNETH RUUD

UiT The Arctic University of Norway, Tromsø

"If you do not understand the ocean,
you do not understand the world."

Fridtjof Nansen to his students (1918)[1]

More than 100 years after Fridtjof Nansen noted the importance of understanding the ocean, we still know less about the ocean than space. There are multiple questions still to be answered, there are processes occurring due to climate change that need to be understood, there are tipping points that need to be identified and adaptations that need to be made. The questions are complex in general, and since the oceans are interconnected, changes in one region influence oceans globally, increasing the complexity even further.

How can universities in the Arctic contribute to knowledge about the Arctic Ocean? There are four major work areas for universities which define the potential for contribution: Education, Research, Dissemination and Outreach, and Innovation. Within these areas and aimed at addressing the challenges facing our oceans, we illustrate the discussion with examples of activities at our home institution, UiT The Arctic University of Norway.

EDUCATION

An educated population is the best foundation for knowledge-based decisions and governance in the Arctic region and for understanding the necessity of decisions that may change the lives of people living in the Arctic. Education that instils deep knowledge about oceanography, marine ecosystems, sustainable use of wild fish stocks and aquaculture, economy, technology, laws and regulations, pollution, new resources in the ocean or beneath the seabed is a prerequisite both for understanding the ocean and for sustainable use of ocean resources. The candidates from our university will go on to work in marine or maritime businesses, ocean policy or research institutions such as universities, taking important recent advances in knowledge further and establishing new knowledge about the ocean. The Arctic must meet future changes with

[1] Harald Dag Hjølle, personal communication. Hjølle, a historian at the Norwegian Polar Institute, has published two volumes on Fridtjof Nansen.

preparedness and robustness. Arctic resilience implies that the people in the Arctic must be prepared for change in ways that keep the region alive and prosperous for future generations of Northerners as well. An educated population is a population that can tolerate and cope with changes. It is also a population that respects the traditional knowledge from Indigenous Peoples living in the Arctic.

Universities in the Arctic must work hard both to recruit a high proportion of young people for university education and to bring them back if this education takes place outside the Arctic region. UiT has tracked their candidates for 3 years after graduation and about 70% continue to stay and work in the North, all in positions where their education has proven to be relevant. Education in Arctic universities must be both modern and relevant to Arctic conditions, but also have global relevance. Example 1 describes a relevant and modern education program in fisheries and aquaculture that is relevant for candidates in the North, but also applicable worldwide.

Example 5.1: Innovative new educational program meeting the needs of the future: SimFish—fishery and aquaculture

In the fishery and aquaculture industry changes are common and, in many cases, unpredictable. The plethora of factors the industry may have to face include, for example, variability in weather, climate warming, range changes by commercial species, harmful algae blooms, invasive species, export controls or embargoes and pandemics. It is important that our candidates know how to meet such challenges (photo 5.1). SimFish is a multidisciplinary learning

Photo 5.1: North Norwegian fishing boats compete with hungry whales: sharing resources.

Example 5.1 *(cont.):* Innovative new educational program meeting the needs of the future: SimFish—fishery and aquaculture

program taught in the fishery and aquaculture bachelor course and designed to provide the students with the competences described. As part of their education, the students are asked to solve complex challenges drawing on a broad range of expertise from the fields of chemistry, biology, technology, economics and governance. SimFish started in 2016 and is built around three key elements.

Photo. 5.2: Students participating in the SimFish game.

1. *Fishery and aquaculture science in practice.* Students visit businesses and organizations in the field of fishery and aquaculture in order to get hands-on and realistic training that helps them understand the opportunities and challenges in the seafood sector.
2. *The SimFish model:* Student-active research and problem-based cases. The model is built around the students simulating real world problems based on scenarios taken from the seafood industry, from policy, from governance, from environmental dilemmas and from society at large. The study program combines traditional tools with game-based learning, and student-active projects in collaboration with the seafood industry. The models use the latest communication platforms, including theoretical and practical approaches, that can also be transferred to other study programs at the university (photo 5.2).
3. *SimFish game*: game-based learning. The game simulates real challenges which can be solved with the tools provided to the students in the traditional teaching situations. The challenges need multidisciplinary approaches to be solved and complexity increases as the students' progress through the program. This approach is particularly effective at illustrating that many decisions are interdependent and that compromises in many cases need to be made using all available knowledge. The game also illustrates the consequences of making wrong decisions.

Note: For a full description see https://uit.no/prosjekter/prosjekt?p_document_id=448448

RESEARCH

Teaching at universities is research-based. This means that each topic taught is based on research and that the education should also empower the students to use research methodology in addressing new problems. Universities focus both on basic research—this being the foundation for increased understanding of the ocean, climate and the changes caused by climate change—and on research that is more applied, for instance in the sustainable use of resources from the ocean. In a time when fast and pronounced climate change is taking place, research aimed at understanding these changes is crucial both for halting or mitigating changes and for adapting to changes that do take place. There are three ocean-related areas where UiT has taken a leading role in research and education, namely in marine biology/ecology/fisheries, law of the sea and climate science. Fisheries is the second most important business in Norway with an export value exceeding EUR 10 billion per year. Both fisheries and aquaculture are dependent on a detailed understanding of ocean ecology, fish behavior, of changes in ocean temperature, acidification and of fish welfare for improved product quality. Researchers at UiT provide knowledge in these fields. Through these efforts, a future with sustainable fisheries and healthy food may be secured using the knowledge generated at universities across the Arctic and across the world.

Likewise, the Norwegian Centre for the Law of the Sea is working on developing a knowledge-based framework to help ensure a legal framework can be put in place in a way that helps secure peaceful collaboration on new opportunities offered by the ocean and in coastal areas that may become accessible due to climate change. Also, in order to keep fish stocks sustainable, fisheries must be regulated in all parts of the oceans through international laws and regulations.[2] Many researchers at UiT work on climate-related topics. One of our Norwegian centers of excellence, the Centre for Arctic Gas Hydrates and the Environment (CAGE), studies release of methane from the seabed and thawing tundra when the ice coverage or permafrost disappears. Methane is a powerful climate gas which may accelerate climate change when it reaches the atmosphere. In all three areas mentioned, many skilled candidates at bachelor, master and PhD level graduate from UiT.[3]

To help monitor sea coverage, sea vessel operations, oil spills and other sources of pollution, the Centre for Integrated Remote Sensing and Forecasting for Arctic Operations (CIRFA), a Norwegian center of research-based innovation, has been established as a knowledge hub for research and development on Arctic surveillance technologies, with leading expertise in disciplines such as remote sensing, signal processing, radar technology, remotely piloted aircraft systems technology, data assimilation and numerical modeling. CIRFA builds on broad competence in remote sensing, and takes advantage of the considerable infrastructure that has been built up in Tromsø in recent decades. The center works in close collaboration with partners from innovative industrial firms and public enterprises.[4]

Other excellence clusters at UiT address climate change more generally. Researchers at the Hylleraas Centre for Quantum Molecular Sciences, another Norwegian Centre of

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[2] For more on the Norwegian Center for the Law of the Sea see https://en.uit.no/forskning/forskningsgrupper/gruppe?p_document_id=355759

[3] For more on CAGE see https://cage.uit.no

[4] For more on CIRFA see https://cirfa.uit.no/

Excellence, explore novel ways of using the climate gas CO_2 as a source of carbon. In this way, the greenhouse gas can be made into useful products and CO_2 can become an alternate source of carbon, substituting the traditional use of oil or gas as source products.[5]

Our university has also made significant investments in excellence clusters that are going to model climate tipping points and biodiversity as well as explore new sustainable energy sources and have also established the Arctic Centre for Sustainable Energy (ARC). ARC acts as an umbrella for several areas of research related to sustainable energy sources, including ethical and societal research. The center engages actively with local communities to explore novel approaches to sustainable energy in small fishing villages that host large fishing industries, using electric microgrids.[6]

Example 5.2: The Nansen Legacy

The Nansen Legacy is a research project designed to understand changes in the marine ecosystems of the Barents Sea when the ice retracts and human activity and other physical and human impacts increase.[7]

The Barents Sea is an Atlantic Water gateway to the Arctic Basin. At the same time, it is located at the receiving end of sea ice exported from the Arctic Ocean. Large-scale patterns of Arctic climate change are fundamentally present, or even enhanced, in the Barents Sea. In 1998–2008 increased heat transported with Atlantic Water caused the sea ice cover to shrink by up to 50%. An increased "Atlantification" of the northern parts of the Barents Sea has taken place, with weaker stratification of the water column and shallower distribution of the warmer Atlantic water. These changes in the physical environment impact the biota, reflected in changed distribution and composition of species and communities. The Nansen Legacy is the collective answer of the Norwegian research community to the unresolved changes witnessed in the Barents Sea and the Arctic Ocean as a whole. The Nansen Legacy constitutes a joint Norwegian research platform to address the following overarching objectives:

- Improve the scientific basis for sustainable management of natural resources beyond the present ice edge
- Characterize the main human impacts, physical drivers and intrinsic operation of the changing Barents Sea ecosystems—past, present and future
- Explore and exploit the prognostic mechanisms governing weather, climate and ecosystem, including predictive capabilities and constraining uncertainties
- Optimize the use of emerging technologies, logistic capabilities, research recruitment and stakeholder interaction to explore and manage the emerging Arctic Ocean.

The Nansen Legacy will provide a 2020–2100 projection of the expected state of the climate, sea ice, and ecosystem, including near-term predictions. It will evaluate the sensitivity and functionality of early-warning indicators used to detect changes in marine resources and

[5] For more on Hylleraas projects see https://www.mn.uio.no/hylleraas/english/
[6] For more on the ARC see https://arc.uit.no
[7] For more on the Nansen Legacy see https://arvenetternansen.com

Example 5.2 *(cont.):* The Nansen Legacy

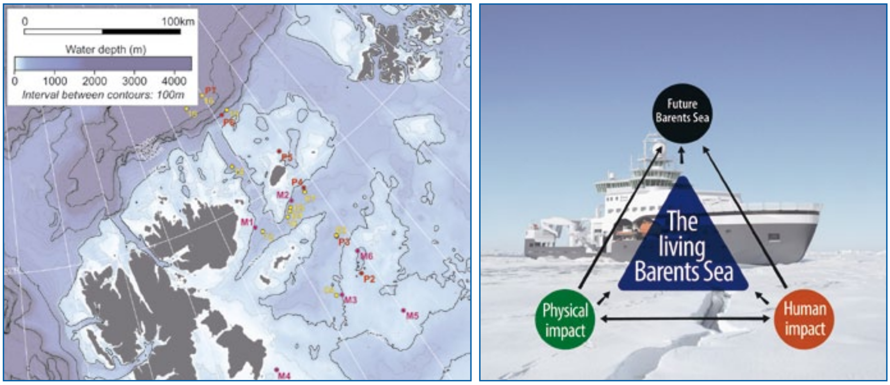


Figure 5.1: Investigation region in the northern Barents Sea and main elements of the Nansen Legacy project. Shown are the stations sampled during fall 2018 for biological and chemical processes and geological core collected for paleo studies *(left)*. The research foci of the project aim for a greater holistic understanding of the hitherto ice-covered northern Barents Sea ecosystem. Its main goal is the living Barents Sea, now undergoing physical and human impacts that will determine the future. In the background *(right)* the new Norwegian icebreaker *Kronprins Haakon*.

their vulnerability to exploitation. Further, the project will improve polar weather forecasts to improve the safety of people and commercial operations. Another core legacy will be the recruitment and training of the next generation of cross-disciplinary trained researchers through a unique national and international network. Overall, the legacy and societal impact will be the scientific knowledge base needed for sustainable resource management in the transitional Barents Sea and adjacent Arctic basins (figure 5.1).

The Nansen Legacy team is deliberately interdisciplinary. Contributors include physics, chemistry, and biology researchers from eight Norwegian governmental institutions and two private research institutes. The institutions include universities, management-oriented institutions, the national weather service, and research institutes with close collaboration with industrial partners. The joint effort offers a human capacity of 3,590 person-months, corresponding to 50 full-time positions of dedicated scientists and support staff over a 6-year period. Moreover, the Nansen Legacy makes available over 370 days of ship time, primarily on the newly launched Norwegian ice-going research vessel, RV *Kronprins Haakon*, enabling the collection of unique, synoptic and interdisciplinary seasonal and inter-annual time series data. The Nansen Legacy field component uses a combination of ship-based, moored, and autonomous technological platforms. To increase high-resolution observational capabilities leading to an increase in future forecast reliability, the Nansen Legacy will develop, test and apply novel advanced technologies in ice-covered regions.

Fridtjof Nansen overcame scientific and physical boundaries by challenging conventions, being unconstrained in his approach to science and to exploring nature in the field and making full use of available human and logistical resources. In the spirit of Nansen, the Nansen Legacy collaborates with relevant national and international research projects and initiatives to utilize complementary knowledge, share infrastructure, increase the scientific outcome and strengthen science networks.

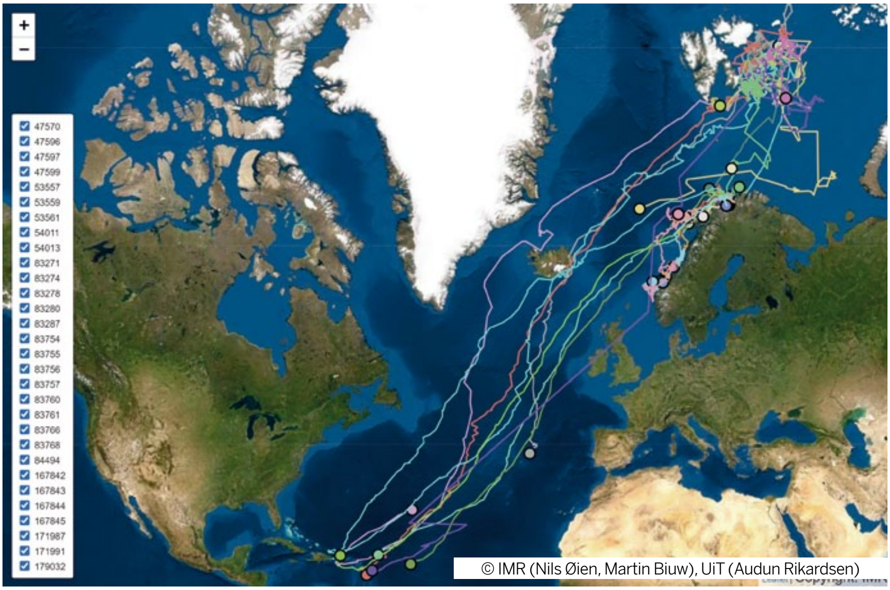
OUTREACH AND DISSEMINATION

Outreach and dissemination are the third pillar of a modern university. This means communication within academia and communication to policy makers and to the public in

Example 5.3. Whale tracking. Follow the whale migration

Since 2010, some fjords in Northern Norway have been the site of an absolutely unique natural phenomenon in the darkest winter months. Huge schools of herring have for some unknown reason migrated into these fjords, followed by vast numbers of whales and, in turn, by fishing and tourist boats, birds and other fish. Since 2015, researchers at UiT have satellite tagged about 50 individuals of each whale species and also made the tracks of these individuals available in real time on internet, giving everyone the opportunity to follow their amazing migrations. The results from this project have given new and unique information on the whales' biology, seasonal migrations and human interactions, information that has been well documented in several national and international TV programs, books and magazine and internet articles. Because these whales follow the herring during large parts of the year, they also indirectly give us information on herring migration, and therefore we can identify changes in this important key species in the northern Atlantic (map 5.1).

UiT The Arctic University of Norway has led the Whaletrack project, in close cooperation with the Institute of Marine Research (IMR) and other national and international partners. The project is supported by the Regional Research Fund, VISTA, UiT, the Fram Center and IMR.



Map 5.1: Satellite tracking of whales across the northern Atlantic as shown on the open real-time tracking portal.

Note: Whale tracking website can be found at https://sa.uit.no/prosjekter/prosjekt?p_document_id=505966 general. There are multiple channels of communications, and universities use them all. Outreach is important also to create excitement and engagement about research, so also helping to recruit young people into higher education. It is important that knowledge is made available to all, particularly so for small Arctic communities where research institutions may be fewer and restricted in scope. This is one of the reasons UiT is strongly supporting Open Access and Open Science. It is important that the latest research-based knowledge is available to all, as clearly illustrated with the recent Corona virus pandemic. This is no less true for research on the ocean.

Example 5.4. Carbon capture and utilization (CCU): Mass cultivation of diatoms and upscaling to industrial level

This project has grown out of an earlier microalgae mass cultivation pilot project and has now turned into a project aimed at upscaling the technology to industrial scale. The project concept includes production of diatom biomass by sequestration of CO_2 and NOx from factory fumes and differs from other conventional initiatives with respect to the choice of organisms, photobioreactor type, illumination, cultivation technology and processing. The main end-product, algae biomass, is fish feed, but bioprospecting and other applications are included. The initiative is integrated into the production line of a ferrosilicon plant (Finnfjord Ltd). The world's largest closed photobioreactor (300,000 L) is installed and upscaling to even larger bioreactors is ongoing. The goal is to make Finnfjord Ltd the first CO_2-neutral ferrosilicon plant in the world, with an added valuable production of fish feed. Today, fish feed contains up to 30% soybean proteins and oil. Production of fish feed using marine resources will replace soybean and include marine oil and proteins in the feed. This will also allow soil, currently used to grow soybeans for fish feed, to be used for producing food for humans. At the factory, a new laboratory and working facilities have been installed which will function as professional meeting places for scientists and students from UiT and external partners (photo 5.3).

Photo 5.3: Upscaling diatom production and CO_2 and NOx sequestration at Finnfjord Ltd.

Note: FM2 research page can be found at https://uit.no/research/micro

In addition to access to research literature, the best way of ensuring that research results are adopted across the Arctic is to involve local researchers and local citizens in the Arctic. Citizen science and responsible research and innovation are therefore key concepts to ensure that we can develop and grow resilient Arctic communities.

INNOVATION

In order to meet future challenges in constructive ways, research results have to be understood and implemented. Students and employees have to learn innovation and entrepreneurship to make smart and sustainable choices and help transform Northern societies into regions where sustainability is strengthened by maintaining and developing thriving businesses and industries. The combination of knowledge from basic research and applications for smarter production is key to making such transformation possible.

CONCLUDING REMARKS

Universities are key to developing a society. Universities in the Arctic area secure the education of candidates needed to develop these remote regions in a sustainable manner and with region-relevant skills and information. The notion of a university in the northern part of Norway was first put forward by a Norwegian businessman in 1918. His idea was to educate local young people with an interest in developing and living in the North. It took another 50 years to develop his ideas into a decision by the Norwegian parliament to establish a university in Tromsø. Many politicians and academicians were skeptical, and few believed that the university would be a success. They were wrong.

UiT is today a comprehensive university with almost 17,000 students and 4,000 staff. Located at 69 degrees north, it is the northernmost university in the world. More than 65,000 candidates have been educated and candidates from the university can be found in all municipalities, all county administrations and most of the businesses all over northern Norway. The population of Tromsø has more than doubled. Many businesses have been created based on research results and large companies have chosen to establish offices in Tromsø close to UiT.

The establishment of UiT The Arctic University of Norway has proven to be one of the most significant political decisions ever made to develop northern Norway. Its success has been the result of long-term commitment by the government and a large number of industrious and committed staff members. Similar success stories can be found across the Arctic and should be used as models to further develop regions in need of universities and increased independence.

The universities across the Arctic region are key players in providing research results beneficial for the North. In this way they secure a sustainable future for the Arctic, with positive global ramifications. The universities in the Arctic are also essential for contributing to a better, holistic understanding of the Arctic Ocean and its sustainable use of resources, how human activities affect marine life, and in turn, the Arctic communities and people of the Arctic. Collaboration across the Arctic is in this respect not only desirable, but indispensable.

CHAPTER 6

RECIPES FOR A FLOURISHING ARCTIC

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BACKGROUND

To describe a reasonable scenario of the Arctic Ocean (AO) at around the end of this century one needs to consider current knowledge acquired through decades of scientific research as well as intuitive constructions emanating from personal ideas and perceptions, among other possible influences. Given this, and after considering the influences of the trident of power, i.e., Governments, Private initiatives, and the doings of Societies (GPS), one can start to visualize a plausible future Arctic. On the basis of the dramatic changes recently observed, this rational-intuitive exercise requires that knowledge gained over recent decades should be taken as a point of reference or baseline from which one could visualize a plausible future. But, this is difficult because processes in the Arctic evolve non-linearly and because the pace of Arctic change is currently the fastest on the planet and also the fastest in the last 65 million years. Thus, visualizing a future Arctic and informing decision-makers, planners, and strategists requires knowledge about change and decisions that can deal with that change. Using information acquired twenty or even ten years ago might not result in well-informed decisions today.

It is therefore important to consider GPS-driven alternative pathways leading toward a flourishing Arctic in particular and a flourishing planet in general, a process that needs to consider certain natural limits as noted by international scholars (Jørgensen et al. 2015). In this context, we must further consider that today's Arctic is in transition and that it is not in a "new normal" or stable state. Change continues to happen at a faster pace than ever before and is projected to accelerate. Given the physical, chemical, biological, and social changes being observed, and the current pace of change, it is important to continuously evaluate our current understanding and knowledge in order to

Note: The views expressed herein are solely those of the authors and do not necessarily represent those of the United States Government, the US Department of the Interior or the Bureau of Ocean Energy Management.

responsibly inform decisions, plans, and strategies. The highly non-linear nature of the biophysical and chemical interconnections that hardwire the Arctic System add to this need for continuous evaluations and learning. If we, as a community, wish to better understand the functioning, evolution, and the overall role of the global climate system, then we must be able to address and manage socio-ecological change as the norm rather than the exception.

BROAD VISION OF THE FUTURE ARCTIC

A warming climate and a growing global population will increase human presence in the Arctic region, especially along its extensive coastline, and newly open and accessible waters. The combination of private investments and government initiatives will be modulated by varied societal demands ranging from conservationism to new and enhanced demands for goods and services. Altogether the Arctic region will see increased human presence and access to and extraction of local resources, although with different

Photo 6.1: A good example of the international collaborations needed in the Arctic region was the 2018 OUTREACH expedition hosted by UiT. The contingent included 25 representatives from gubernatorial, private, and academic sectors of several Arctic nations. Over one week and onboard the *Helmer Hanssen* vessel, the participants held daily meetings to discuss international research priorities, how to clear barriers preventing progress, and how to build resilience through increased connectivity across nations (Auad et al. 2018a). In this photo the participants visit the former settlement of Smeerenburg at 79°43′54″ N 10°59′42″ E, in northwestern Svalbard, Norway during June of 2018.

regulations and policies across nations. Updating these peripheral and guiding social elements, e.g., legislation and policies, to address emerging challenges and opportunities, will be of fundamental importance to achieve success with respect to our adaptation as humans. This must include responsible management of the natural resources on which we all depend. These and other public or private enterprises will certainly be affected by the seasonal variability of the Arctic's environmental conditions and effects on humans and their activities. The natural carrying capacity of the region is low, which means times to recover from disturbances could be generally longer than in other places. When this is considered along with the fact that a variety or resources may be tapped, in an area with very harsh conditions, a very strategic and knowledge-based approach to land and resource management is called for.

The harshness of Arctic winter conditions will remain challenging during global warming. Furthermore, the seasonal availability of natural light from April through October is certainly relevant for agriculture and solar energy generation and will thus influence the ratio of permanent to seasonal newcomers to the region which will define new socio-ecological trends with respect to the present time. Extreme variability in light availability will deter some, attract others, and lead others to adapt once in the Arctic. This will involve a number of socio-economic considerations affecting a variety of fields, including, but not limited to education, jobs, and overall personal values and perceptions. Despite some of these and other challenges, the coastal Arctic environment will present numerous social-ecological motivations for humans to slowly populate the High North, including but not limited to the search and exploitation of natural resources, industrial activities, research, recreation, and support of geopolitical strategies.

MAIN DRIVER

As happened with many human displacements hundreds and thousands of years ago, climate change will be enabling one of the greatest drivers in mankind's history: human demand for goods and services. How might this happen? From the environmental perspective, competing theories have been proposed for how the future Arctic will be characterized in its socio-ecological structure and functioning. For instance, increased temperatures and river runoff will both contribute to higher stratification in the upper layers of the ocean, while in contrast reduced sea ice cover would favor increased mixing of surface waters by wind. While this is still open to debate in the open AO, its shelf and coastal waters would likely remain mildly to highly productive due to a spatial reorganization driven by current warming trends. This reorganization processes would be favored by a number of factors including but not limited to fluvial discharge of nutrient-rich waters and wave-induced sediment and nutrient re-suspension in shallower areas, while coastal erosion will also introduce additional nutrients at the land-sea boundary.

These processes would be further modified by changes in ecosystem structure and diversity as species previously absent or rare start to arrive and compete for resources in the coastal domain. These (new and old) species populating the future Arctic shores include those in the marine, terrestrial, and aerial environments, and will establish new trophic and non-trophic interactions. In the coastal marine environment where low salinity waters are the norm, anadromous species (salmon, char, cisco) are often found migrating (Carmack and Macdonald, 2002). The future AO might thus host a sea-land-air coastal biological hotspot, or hotline, with an increase in biodiversity at least with respect to that seen late last century. A few factors would contribute to this: a) the northward migration of several marine, terrestrial, and avian species, b) the reduced availability of sea ice which will further increase this convergence of species along Arctic coastlines as polar bears, walruses, and other ice-dependent species will congregate and spend longer times on the shores. This has already started on land and in the ocean where shelf-break areas are also predicted to grow in terms of productivity levels. For terrestrial species, the coastline will act as a natural barrier thus favoring a convergence at the sea-land interphase. We have started to witness some consequences of this: in 2006 the first hybrid polar/grizzly bear (a.k.a. Pizzly or Grolar bears), was sighted in the Canadian Arctic. Many more sightings followed that first occurrence. Concomitantly, Indigenous subsistence hunters in the Canadian High Arctic started to report a shift in the diet of seals trapped by them, as revealed by their stomach contents. This diet flexibility contributes to ecosystem resilience and is triggered by the spatial reorganization of different ecosystems (commonly dominated by changes in temperature) which also suffer important changes with respect to the amount of energy invested in feeding. These adjustments, reorganization, and re-hardwiring of Arctic elements will certainly test its adaptive capacity to the cumulative effects of multiple stressors including the potential arrival of non-native species.

MANAGEMENT AND LEGISLATION

The Anthropocene is marked as a geological epoch of acceleration, in which a multitude of fast changing variables have "turned the corner", e.g., human population, fertilizer application, groundwater withdrawal, loss of tropical forest, coastal zone structures, GDP, foreign direct investment, cell phone adoption, etc. This pace of change happens faster than our norms, ethics, institutions, and knowledge can adapt. What worked in the past to address environmental resource management likely will not in the future. Current estimates of environmental conditions of a future Arctic have an associated uncertainty partly rooted in the limitations of climate models that simulate and predict some of the dynamics of the climate system.

These limitations include poor simulation of fast change, tipping points, the role of biological processes, poor characterization of feedback processes, and cloud dynam-

Photo 6.2: The northernmost Russian settlement of Pevek, at 69.7 N, exemplifies how socio-economic linkages can develop at high latitudes. Pevek's economy is and has been strongly dependent on mining activities since the early 1930s. With a growing global population and warming temperature trends, larger and new settlements would be fairly common in the future Arctic.

ics, among others. For instance, depending on whether current atmospheric dynamics would lead to significant changes in the formation of either high or low clouds, different scenarios with different trajectories would characterize the future Arctic in particular and the globe in general. The latter example would also be dependent on the season in which such cloudiness changes would be prevalent. Depending on these alternative climate pathways different dynamics and states will emerge for regional and global temperatures, wind patterns, and for the global hydrological cycle.

One thing seems clear, however. Change will be the norm and change will also be affected by future legislation and policies. The adaptability problem to fast and dynamic environmental change has not yet been properly addressed, at least in practice, because current laws are static and were written decades ago using concepts and knowledge that we now know to be outdated or incomplete. For example, some environmental laws in the United States were written using scientific knowledge from the 1960s and '70s.

If we remain in a business-as-usual scenario, then there will be a mismatch between static legislation and policies and their desirable outcomes, as they attempt to paradoxically bound a rapidly changing socio-ecological system (SES) in the Arctic region. These would be additionally impacted by dissimilar management approaches to conservation and exploitation of natural resources by the different Arctic nations. This problem can even arise within a single country where federal, state, tribal, and local agencies need consistency when coordinating their respective management approaches across different spatial scales.

Anything that happens in the new Arctic will be in the context of events in a new Earth system, in which institutions and governing organizations will be pressured by a host of new challenges. The existing Arctic Council provides a platform where nations may possibly be able to foster the new ideas and consistent approaches that will certainly be needed. It is encouraging that this international forum was already able to produce three legally binding agreements on three different activities: 1) science cooperation, 2) marine oil pollution preparedness and response, and 3) search and rescue. Although not written to address current changes, untapped legal concepts in existing legislation could come to bear fruit in future management initiatives. Along these lines, it has been suggested (Auad et al. 2018b) to re-interpret the concept of "harmony" in the National Environmental Policy Act of the United States. Many others have advocated for reflexive legislation (Orts 1994; Garmestani, Allen and Benson 2013) as an effective way to handle socio-ecological issues commonly characterized by dynamic and non-linear behaviors (Garmestani and Benson 2013). The two options are not mutually exclusive and could be developed sequentially or simultaneously to properly address environmental concerns across the Arctic.

TRADITIONAL KNOWLEDGE

Traditional knowledge, which includes Indigenous knowledge, has been and remains a powerful source of information, not only for local communities that depend on it to subsist but also for scientists, who use it to complement their scientific research, and for US Federal agencies, who use it to inform some of their decisions (Kendall et al. 2017) on resource management. Traditional knowledge (TK) has been collected for centuries when both the pace of change was dramatically slower than it is today and change was driven by non-anthropogenic drivers. Because of this, faster learning and updating would be required now and tomorrow to ensure it remains useful to the communities that rely on it for making varied decisions. If not, sadly, TK could become one more casualty of global warming. For example, while TK remains a very powerful knowledge source for detecting change, and given recent reports from Indigenous Peoples and scientists,[1,2] there are

1 Maija K. Lukin's presentation at Arctic Futures 2050 Conference, Washington DC, September 2019: https://www.youtube.com/watch?v=PEWHFx0950g&feature=youtu.be

2 Henry Huntington, personal communication.

still some open questions about the need for continuous updating of TK to keep up with the current pace of change. This is crucial to ensure the safety of local communities and also for them to continue having reliable access to subsistence sources and safety. Co-producing and updating current knowledge among local communities, scientists and governments would need further collaborations and adaptation in order to build resilience at multiple scales. These challenges are being exacerbated by the known lack of interest/motivation of new Indigenous generations in assimilating TK from their elders. Therefore, we emphasize that adaptive approaches and resilience-centered goals are needed more than ever at local and pan-Arctic scales.

RESILIENCE FACTORS AND ADAPTATION

In response to these changes, more emphasis must be placed on advancing our understanding of socio-ecological resilience factors—those already identified and those being predicted—for the Arctic region. This includes understanding and preparing for the natural system dynamics of growth, conservation, disruption, and reorganization. Dominant neo-liberal economic approaches, which had a focus on growth over resilience, contributed both directly and indirectly to the current and changing state of the Arctic and of the entire planet. Market-motivated efficiencies lead to certain positive out-

Photo 6.3: Polar bears and grizzly bears have started to cross-breed since at least 2006. The resulting Pizzlies, or Grolar bears, are now an icon of a changing socio-ecological system in the Arctic region.

comes, but at the expense of resiliency and redundancy. Due to path dependencies and irreversibility, resilience will not mean simply returning the Arctic to a previous state but rather anticipating novel conditions and relations, such as those described above. Going forward, the Arctic would benefit from aspects that promote a regenerative economy (Fath et al. 2019) featuring reliable inputs and healthy outputs (i.e., clean, sustainable fuels and resource flows), as well as improved network structures that capture scaled and mutualistic patterns of organization.

A regenerative economy takes its cues from nature aiming for a style of eco-mimicry. One challenge in the Arctic is that the scanty nature of resources tends to streamline activities regarding ecological (as apparent in less diverse food webs), social (lower population and footprints), and economic (fewer business niche opportunities) domains. A resilient approach will holistically consider the interaction and interplay of these three critical domains. This will require new connections and collaborations that can tap into self-organizing and self-reinforcing cycles that provide healthy positive feedbacks as well as adjust for elements within all domains. Changing and warming conditions open new possibilities that need to proceed in tandem with an expanded awareness of how to manage for integrated system resilience. Ongoing resilience research in ecology gives guidance on how to measure and manage dynamic systems along an adaptive pathway that balances efficiency and redundancy (Goerner, Lietaer and Ulanowicz 2009; Fath, Dean and Katzmair 2015). Aiming for and achieving a balance between system rigidity and system brittleness would need to be considered in international agendas as a requisite to maximize pan-Arctic sustainability.

Legislation and associated policies would also require adaptive approaches able to address cross-scale challenges and opportunities in order to provide a consistent context for effective, responsible, and defensible decisions. Embracing dynamic policies and reflexive legislation would be necessary to consistently couple spatial scales in such a way that regulating (at large scales) self-regulation (at regional to local scales) would provide both much-needed control and autonomy, respectively. A reflexive legislative approach is therefore advocated here in which a broad pan-Arctic international law would regulate regional and local self-regulative initiatives. In this manner, Arctic governments would be able to have top-down regulation efficiently coupled to bottom-up self-regulation, thus providing needed flexibility and adaptation capabilities to local communities at relevant scales. In this way, managers and decision-makers will be able to implement important decisions through adaptive governance practices (e.g., the use of bridging organizations) and the selection of tailored decision-informing tools for each jurisdiction and situation.

To further increase the resilience of the Arctic system, it is also important to consider adaptive governance and associated management decisions as complementary elements of a dynamic framework that includes reflexive legislation and cross-scale socio-ecological resilience as an overarching goal. While adaptive governance will enable consistency across jurisdictions (complementary and/or overlapping), different decision-analysis tools can be considered for different scales. For an increased probability of success, these tools would need to be selected for each case and scale, and based on the uncertainty of the problem and the controllability of the outcomes in question. Along these lines, it has been concluded (Auad et al. 2018b) that a combination of adaptive management and an iterative scenarios method are the best approaches to inform decisions at small and large scales, respectively. While their particular analysis focused on a specific organization regulating offshore energy, other cases might also need to consider supplementary factors, such as clarity of objectives. Consistency between analysis tools and type of decisions facilitates robust adaptive strategies.

TWO ARCTICS?

The future AO and vicinity will certainly present challenges and opportunities to all that live there. Settlement of humans will be challenged from several angles. For example, thawing permafrost will present a constant threat to infrastructure. Human-nature interactions will be both risky and heavily regulated in the sector west of about 30°E to the Bering Strait longitude. The Russian portion, eastward of about 30°E to the Bering Strait, would be more heavily populated and with significantly different regulations. Based on this and depending on the path followed by the combined global effect of the GPS trident, it would not be surprising to find two different socio-economic structures and regulatory styles along the shores of the future Arctic. Partly because of this, new and enhanced existing ports will add further stresses in response to increased shipping traffic and coastal populations. Both areas will show an increased number of humans with respect to current numbers, albeit with diverging demographics, ecological characterization, and socio-economic statistics. This could create challenges for natural resource management, international conflicts, and therefore pose a threat to the overall socio-ecological resilience of the Arctic region.

CONCLUDING REMARKS

Under current socio-ecological trends, the future Arctic will face increased human presence and activities with a continuous re-hardwiring of old and new elements. This will increase the probability of increased pollution and disease—there were cases of COVID-19 in Greenland—and will undermine SES resilience in the region. Transformation of many coastal areas could result in biological hotlines (shorelines) and/or increased biodiversity there, which would favor additional human-animal interaction, thus creating new challenges and opportunities on many fronts. It remains unclear if an anticipated reduction in caloric needs will be offset by increased burn rates due to food scarcity, e.g.,

Figure 6.1: Conceptualized summary of the main ideas of this chapter. An overcrowded planet and an increased human presence in the High North (passengers on train) produce non-recyclable (over at least a generation) products (smoke off locomotive), and must rely on adaptive dynamics (locomotive wheels as adaptive cycles) to stay resilient when arriving at a crossroads. There, policies and laws (tracks) are decided (lever) by the trident of power or GPS (Governments, Private sector and Societies), which includes Indigenous Peoples. This GPS-driven navigation will altogether define the Arctic of the future and would certainly hope for sustainability. The desirable *(center)* and undesirable *(left)* scenarios are plausible outcomes, while a black swan scenario *(right)* represents situations (desirable, undesirable or in between) that we have not been able to predict, such as the COVID-19 2020 pandemic which is represented in the figure by a 2020 stop or slow down. The desirable scenario includes a highly connected and resilient Arctic achieved through peaceful international adaptive strategies that would need to be implemented soon, and that should be the target of today's decisions. The thick shorelines represent the biological hotlines mentioned in the text. The undesirable scenario *(left)* is characterized by non-uniform regulations and policy styles across the Arctic region, no or little sea ice and a loss of biodiversity. *Source:* Figure modified and expanded after an idea of Carlos Duarte and sketched by Tim Lenton (2013).

longer hunting excursions for several animal species and Indigenous Peoples. But, if the current pan-Arctic contrasts in governance and regulatory styles increase, their impact on SES resilience could result in a loss of sustainability as well as a threat to pan-Arctic peace. A black swan coming from outside the Arctic circle could certainly destabilize decades of peaceful achievements by the Arctic Council.

It is then imperative to launch an international adaptive strategy to unify criteria and approaches, facilitating the adoption of effective legislation, policies, and governance at pan-Arctic and regional scales. This strategy (figure 6.1) would need to build integrated socio-ecological assessments, invoke regenerative economic principles and re-interpret current laws in the short term while promoting reflexive legislation and dynamic policies in the longer term. It would have to identify barriers and vulnerabilities[3] and deliver additional legally binding agreements able to produce efficient and effective resource management decisions. This science-informed and traditional knowledge-informed enterprise will therefore benefit all Arctic nations, build much needed bridges and resilience and pave the way for a collaborative framework able to address current global socio-ecological challenges. The pathway toward a flourishing Arctic needs to be built with resilience as a central goal and ethically, mindful of our legacy to future generations.

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CHAPTER 7

ARCTIC COOPERATION INITIATED AT THE END OF THE COLD WAR: SOME REFLECTIONS ON THAWING AND POLITICAL INITIATIVES IN THE NORTH

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During a sunny walk in early autumn 1993, my wife and I met an old friend and her husband, the former ambassador to Helsinki who at that time was the Secretary General for the Ministry of Foreign Affairs (MFA) Norway. After some small talk, the Secretary General told that he was going to travel with the Norwegian Minister of Foreign Affairs to Kirkenes the same day for an important meeting under the Barents Cooperation. In response to a question about his view on the Finnish initiative regarding an Arctic environmental cooperation "the Rovaniemi process," he stated bluntly: "That initiative should have been stopped!" – "Why?" was the follow-up question. "Because the Finns are interested in claiming the Pechenga corridor back, and we must avoid that happening!"[1]

MELTDOWN OF THE COLD WAR CREATED OPPORTUNITIES FOR ENVIRONMENTAL COOPERATION

After World War II, the Cold War froze the connections between Russia and the Northern Arctic countries. The extensive military activities in the North affected cross border cooperation in areas such as trade, culture and science. In the mid-late 1980s, some reports documented that the Arctic environment might not be as pristine and clean as most people believed. Some of these observations made their way into media, e.g., a front page of a Canadian newspaper stated "Soviet, European pollution threatens health in Arctic" (*Toronto Globe and Mail* 1988). Scientific surveys documented high levels of pesticides such as DDT and industrial chemicals like PCBs in breast milk from Indigenous Arctic women living in the northeast of Canada—an area far away from large industries and agriculture. Emissions of sulfur dioxide and dust particles from large Russian smelters at Norilsk and Nickel in northwestern Russia affected the forest on the Taimyr Peninsula, part of the Kola Peninsula and border areas between Russia, Norway and Fin-

[1] Personal note from 1993.

Photo 7.1: US President Ronald Reagan and the General Secretary of the Communist Party of the Soviet Union, Mikhail Gorbachev, initiated the thawing of the Cold War. Here we see them during their historic meeting in Reykjavik in 1986.

land. In addition, alarming reports about nuclear pollution around military installations in the northwest of Russia was presented (AMAP 1997).

In the same time period, the President of the United States Ronald Reagan and the General Secretary of the Communist Party of the USSR (the Soviet Union) Mikhail Gorbachev started a dialogue to prevent a nuclear war. The talks initiated the thawing of the Cold War. In October 1987, Michael Gorbachev gave a speech in Murmansk honoring the city as "a Hero City" for its stand during the "Great Patriotic War" against the German troops. In his speech, Gorbachev called for a change in the Arctic region—from an area dominated by military activities (USSR and the Warsaw Pact vs. the United States and NATO) having nuclear submarines hiding under the Arctic sea ice ready to attack, to an area of peace, science and prosperity, including a plan for protecting the environment of the North. Gorbachev's speech triggered a range of political and science-related initiatives in the High North, summarized in Table 7.1.

For years, the Finnish government had been searching for signals from Moscow that could reduce the tension between the East and the West and they saw this speech as a possibility for an opening to achieve a significant change in the North. Finnish diplomats developed a plan for establishing an environmental cooperation that could focus on protection of the Arctic environment and reduction of pollution of the North. Intensive exploratory discussions between the eight Arctic countries resulted in an environmental consultative meeting held in Rovaniemi in September 1989. However, the Arctic

Table 7.1: Arctic initiatives established after Gorbachev's speech in 1987

1989	The Rovaniemi consultative meeting
1989	UNEP GRID Arendal
1990	International Arctic Science Committee (IASC)
1991	Arctic Environmental Protection Strategy (AEPS)
1991	Northern Forum (NF)
1993	Barents Euro Arctic Coooperation (BEAC)
1994	Standing Committee for Parliamentarians of the Arctic Region (SCPAR)
1996	Arctic Council (AC)
1997	EU-Northern Dimension
2001	University of the Arctic (UArctic)

countries had different views about the Finnish initiative. Most were in favor, while the United States and Norway were rather reluctant—so skeptical that one of the Canadian delegates at the meeting had to "remind" the Norwegians that "the Cold War was over."[2] Nevertheless, after two years of meetings and negotiations, the Ministers of the Environment from the eight Arctic countries (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and the United States) gathered in Rovaniemi in June 1991 and signed the Arctic Environmental Protection Strategy (AEPS). AEPS focused on Arctic environmental and human health issues including a monitoring and assessment program of pollution, protection of Arctic marine environment, emergency response strategies to Arctic oil pollution, and conservation of Arctic fauna and flora. At the Rovaniemi ministerial meeting in June 1991, several countries planned to offer a home for the core activity for the AEPS namely the Arctic Monitoring and Assessment Programme (AMAP). Norway was first to present an offer to host and finance a secretariat for AMAP in Oslo, and the secretariat has been in operation since 1992.

Already in 1991, during the AEPS negotiations, Canada was pushing for the founding of an Arctic Council (AC), (Smieszek and Koivurova 2017) that would cover a wider area than the AEPS and include focus on the Arctic Indigenous Peoples and security issues. In 1996, the United States finally supported the Canadian initiative and the Arctic Coun-

[2] Personal note from 1989.

cil declaration was signed in Ottawa. The Arctic Council continued the work initiated under the AEPS and added on more focus on Indigenous Peoples and sustainable development but decided not to include security issues. The Rovaniemi process is well reflected by Stone (2015) and Heikkilä (2019).

Another Arctic political initiative at that time was the Barents Euro-Arctic Cooperation (BEAC) established in 1993 in Kirkenes (Denmark, Finland, Iceland, Norway, Russia, Sweden and EU are today members). Norway was the key driver for this establishment and the main motive presented for the Norwegian BEAC initiative was to secure long-term stability, socio-economic development and to reduce possible tension of the region, to a great extent the same arguments used for the establishment of the Council of the Baltic Sea States (CBSS) in 1992. Tunander and Schram Stokke (1994) and Østereng (2012) analyze the BEAC process.

A CRUCIAL CORRIDOR

The Pechenga (or Petsamo) corridor is the land and coastline 100 km east of the border between Norway and Russia, as it used to be before 1917 (map 7.1). In the period 1809–1917, Finland was part of Russia as "Grand Principality of Finland". After Lenin's return from his exile in Switzerland to Russia by train through Finland, Finland achieved independence. As part of the peace treaty of Tartu (1920), the Pechenga corridor, in-

Map 7.1: The Pechenga (Petsamo) corridor.

cluding the coastal area was handed over to Finland. In the following years, rich mineral resources were discovered in this corridor and extraction started e.g., at Nickel (with the help of Canadian technology). During WW2, Finland fought twice against its powerful neighbor, but when the fighting ended, Finland got neither the Pechenga corridor nor the Karelia area further south. Due to these circumstances, Norway again got a border with Russia in 1944.

Why would a Norwegian MFA Secretary General in 1993 be concerned about the Rovaniemi process and the Pechenga corridor? Maybe the phrase "to secure long-term stability" in the Barents region had an extra meaning? A coastal state will have the rights to offshore activities such as fishing, exploration of petroleum hydrocarbons and minerals. If Finland had the Pechenga corridor, they would have Norway to the west and Russia to the east, and thereby the rights to fishing and offshore exploration within their sector. The Barents Sea area in question was to a far extent the "Gray zone", that for several decades was in dispute between Norway and Russia.

A FINNISH THREAT?

During the 18th and 19th centuries several Finnish families in the High North left their homes and migrated to northern Norway, especially to the eastern Finnmark county (e.g., Pasvik) and the northern part of the Troms county (Lyngen, Nordreisa and Kvænangen) (map 7.2).

Map 7.2: Finnish immigrant routes to northern Norway in the 18th and 19th centuries.

Living close to the fjords, people achieved improved food supply from fishing, rather than relying on small farms in climatically exposed northern Finland. The arriving Finns (also named "Kven") settled down and their families have remained in these areas since then. In the early 20th century, the Norwegian government was concerned about these Finnish-speaking settlements. The "Finnish threat", as it was called, is discussed in detail by Ratche (1936) and Eriksen and Niemi (1981). According to these contributions, the main concern at that time was related to the loyalty of these immigrants and the possibility of Finland claiming part of these Norwegian areas. To strengthen their Norwegian identity, schools (e.g., at Svanvik in Pasvik and Solhov in Lyngen) and chapels were built to "Norwegianize" the Kven population. In addition, the government handed out Norwegian books and weekly-illustrated magazines free to families with Finnish background, partly funded by the ministry of defense. The total population today with Finnish or some Finnish background ranges in official documents between 10,000 and 20,000 (Store norske leksikon, online 2020).

Based on the 1993 statement from the Norwegian MFA Secretary General, one may wonder if a kind of a "Finnish threat" was still part of the geopolitical picture for some of the senior civil servants. They may have been concerned about whether Finland, as part of discussions with Moscow regarding closer Arctic cooperation, could manage to get the Pechenga corridor again. The establishment of the Barents cooperation was maybe therefore for these civil servants not only to secure a long-term stability and socio-economic and culture development of the Barents region, but also to keep the borders as they were and to hinder the eventuality that Finland could get control over the Pechenga corridor?

In the years after Gorbachev's speech in 1987, there were rumors in the media that Finland might recover Karelia from Russia, an area Finland lost to Soviet Union during the winter war between in 1940 and again after the continuation war 1941–44. This geographical area was in the 90s no longer populated by Finns but by a million Russians who were longing for a better life. Some Finns were keen to get Karelia back, while the feelings for the Pechenga corridor were not seen in the press. The "forest coffee statement" in 1993 may therefore have reflected a pre-WW2 "Finnish fear" that still was lingering on in the Norwegian foreign policy establishment. A fear that today has thawed forever.

THE SUCCESS OF THE BARENTS COOPERATION

At the Arctic Frontier 2020 conference in Tromsø, the Norwegian Minister of Foreign Affairs, Ine Eriksen Søreide, arranged a side-event "The Barents Cooperation—a success story for international collaboration across borders in the Arctic". The room was filled with people interested to learn her evaluation after 27 years of cooperation. A cooperation where especially Norway, but also the other Nordic countries, had invested a lot of political will and financial resources through central and regional institutions and private businesses. Her conclusion was surprising for several in the audience. The main success was not the multiple business investments that had been tried over the years, but “the people to people cooperation” that had been established. Observed from my position as the former Executive Secretary of AMAP, who had been working both within the Barents region and Arctic circle over 25 years, I agree with the Minister. The contact established across borders between people in Russia and the Nordic countries has matured and continues to function, while most of the financial business investments made over the years after 1993 did not develop as expected due to several reasons.

Moreover, environmental cooperation across borders has achieved important results. Significant initiatives have been taken and implemented by the BEAC and the Arctic Council member countries that have had important effects on reducing the threats from the pollution of the Northern environment and the people. In 1993, a very interesting people-to-people initiative was taken that involved both the AEPS/AC, the BEAC Cooperation and the Nordic Environment Finance Corporation (NEFCO). One of the Director Generals at the Norwegian ministry of environment contacted the AMAP secretariat to clarify if AMAP could perform a screening expert study in northwestern Russia. The mission was to identify pollution “hot spot” projects where joint actions by governments and businesses could reduce the threats both at local and regional level for humans and the environment. The list of hot spots would be used by the Barents Cooperation to raise national and international funding to be spent in cooperation with Russian government and businesses.

After consultations with central and regional Russian governmental institutions including the military, the AMAP Secretariat organized two expert groups mostly composed of Russian experts from military and civilian organizations and some western civilian experts from Finland, Norway and Sweden. The Russian government presented two requests concerning the composition of the groups—no persons from the United States and no western military could be part of the groups. The two expert groups performed surveys in northwestern Russia during the spring of 1995, one identifying radioactivity hot spots and the other identifying hot spots due to industrial discharges to water, emissions to air, lack of sewage treatment, contaminated drinking water, etc. Two reports (AMAP 1995) were produced, one focusing on the radioactivity situation and the other on the other topics. The two reports included a list of 71 projects and were presented to the 1995 BEAC environmental ministerial meeting held in Rovaniemi (Kimstach 2005).

Over the years after this ministerial meeting, several of the hot spots identified have been addressed. The first activity initiated was a small-scale project to provide clean drinking water to the Saami village Lovozero on Kola Peninsula. This project, co-funded by the Karasjok community and NEFCO (Nordic Environmental Finance Corporation) demonstrated that it was possible to work cross border.

Photo 7.2: The barren landscape of the Pechenga fjord. The only ice-free harbour in Finland, Liinakhamari, was situated here from 1920–1944.

The most challenging, but also the most successful people-to-people activity was the clean-up work identified for radioactivity hot spots. After the ministerial meeting in Rovaniemi, a nuclear report giving detailed information about threats from several sources, proposed technical solutions and tentative costs was presented to and well received at the International Atomic Energy Agency (IAEA) and the Contact Expert Group (CEG) at a meeting in Vienna, January 1996. Over the years, several countries and institutions have been involved in the clean-up of spent nuclear fuel and waste storage sites, improved safety operations at the Kola nuclear power plant and decommissioning of 122 nuclear submarines in northwest Russia, thereby reducing the threats for significant accidents and radioactive pollution.

The initiative for this clean-up cooperation came from Norway and the Barents Council Cooperation. The screening was performed by AMAP experts in close cooperation with Russian ministries, agencies and military units, especially the Russian navy and the shipyard in Severodvinsk. The funding for implementation of all the projects came from several countries and institutions, e.g., in Russia, Norway, the United States and the European Union. The whole process is an example of a rather complicated and successful cooperation cross northern borders and political interests due to the political initiatives taken by leaders at that time.

LESSONS LEARNED FROM THE ARCTIC COOPERATION

When the Arctic Cooperation started, there were rumors regarding pollution and that the main source was in Soviet Union. Scientific assessments have documented that part of the Arctic areas and its population was exposed to serious pollutants, but the source was not only the Soviet Union. The pollutants came to the Arctic by wind, rivers and ocean currents from industrial and agricultural areas all over the Northern Hemisphere (AMAP 1997). Therefore global actions were needed and taken, e.g., through UN Environment.

Several places on the globe have high tensions between neighboring countries due to territorial conflicts, but also harmful cross-border pollution affecting environmental and human health. For these regions, there are some lessons to be learned from the Arctic process, on how to achieve cooperation across borders that can improve not only the environmental and human health situation, but also reduce political and military tensions.

Although there were some tensions during the initiation of the Arctic cooperation, both the Arctic and Barents Councils have contributed to reducing the political and military tension in the North, reducing pollution of the environment and improving the human health situation by actions taken at local, regional and global levels. Some of the important factors for the success have been:

1. A political will and engagement of the people in the North.
2. Engaged scientists and experts from all countries covering relevant disciplines.
3. Focus on high-quality work and transparency.
4. Allocation of financial and human resources.
5. Preparation of policy relevant recommendations based on science.
6. Establishment of permanent secretariats to support the work over the years.

Today the Arctic Council is the lead political body within the Arctic with 39 observing countries and organizations. It has a permanent secretariat in Tromsø. The Barents Euro-Arctic Council has nine observing countries and has a secretariat in Kirkenes. Even with limited human resources important achievements were made.

Looking back over the successes of Arctic and in particular Nordic cross border environmental cooperation one cannot but be impressed at how effectively Nordic nations overcame their historical concerns 25 to 30 years ago, took the moral high ground and seized the opportunities envisioned by Mr. Gorbachev.

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CHAPTER 8

PREVENTING UNREGULATED FISHING: THE CASE OF THE CENTRAL ARCTIC OCEAN

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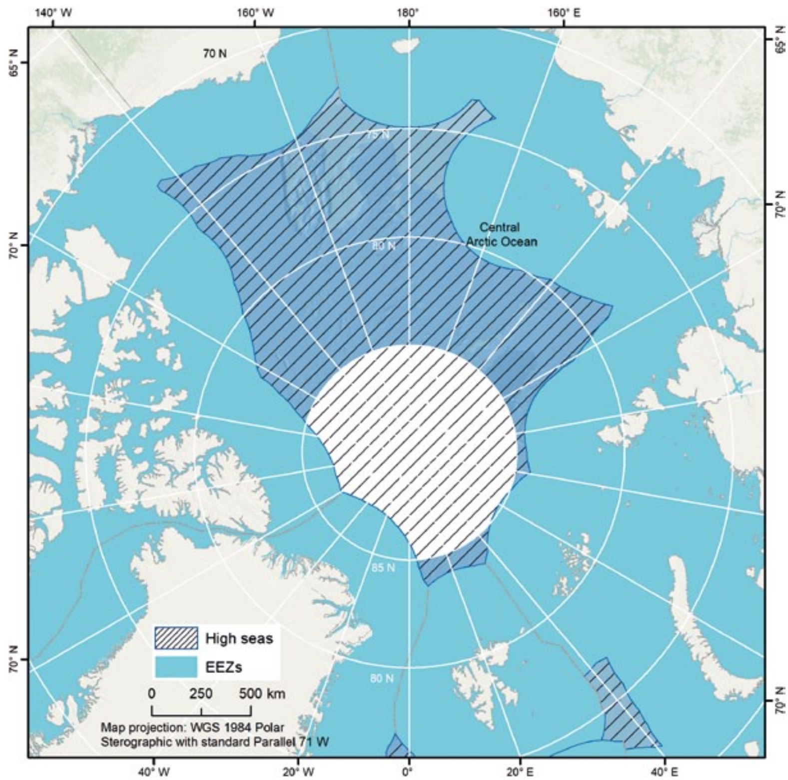
One of the major themes of international fisheries cooperation in the 2000s has been the struggle to contain and eradicate illegal, unregulated, and unreported (IUU) fishing. A novel approach to confront unregulated fishing has been developed for the Central Arctic Ocean (CAO). The CAO is situated to the North of the land territories of the Arctic, surrounded by the five coastal states the Russian Federation, the United States (Alaska), Canada, Denmark/Greenland, and the Kingdom of Norway. In late winter almost the entire CAO is covered by sea ice, altogether some 15 million km^2, and in late summer the ice-covered area has shrunk to about 5 million km^2. In the middle of the CAO there is a high seas area, beyond the 200 nautical mile (nm) zones of the coastal states (map 8.1). This area is some 2.8 million km^2, larger than the Mediterranean. This is a deep-sea region, covered by ice large parts of the year. No fishing occurs there. Nevertheless, an international agreement for the prevention of unregulated fishing has been negotiated for this high seas area, signed in 2018 and likely to enter into force soon.

FISHERIES IN THE HIGH NORTH

In the sub-Arctic seas surrounding the CAO there are major fisheries, based on the rich marine living resources in the sub-Arctic regions, where some of the most important fisheries in the world takes place: the Bering Sea, the Barents Sea, the seas around Iceland and Greenland, and the Northwest Atlantic between Canada and Greenland (Hoel 2018). The world´s northernmost commercial fisheries take place in the Barents Sea, up to around 80 degrees north. The pollock fisheries in the Bering Sea (US and Russia) and the cod fisheries in the Barents Sea (Norway and Russia) are among the largest whitefish fisheries in the world.

Large fish stocks need large habitats. The warming of ocean climates that brings warmer waters and less sea ice has made it possible for fish stocks to expand their habitat northwards. This, in turn, has brought speculation that commercially viable amounts of



Map 8.1: The Arctic Ocean. The shaded area is the 2.8 million km² high seas area in the Central Arctic Ocean that the agreement to prevent unregulated fishing applies to. The map was constructed by associate professor Kehsav Prased Paudel at the Norwegian College of Fisheries Science, UiT The Arctic University of Norway.

fish could also expand into the CAO. For a fish stock to expand into a new area, a number of conditions have to be met: there must be food for the fish, bottom topography has to be suitable (for groundfish), and spawning grounds must be within reach (Hollowed, Planque, and Loeng 2013). On the basis of such criteria there seems to be little probability of groundfish such as cod and haddock moving into the deep-sea areas in the CAO. Pelagic species such as polar (Arctic) cod *(Boreogadus saida)* may however do so.

COMMERCIAL FISHERIES IN THE CAO?

The 2005 Arctic Climate Impact Assessment (ACIA 2005) brought to the world´s attention the accelerating reduction of sea ice in the Central Arctic Ocean. In the wake of this, a concern emerged that the large fish stocks in the sub-Arctic seas could expand northwards into the CAO, and even into the high seas when summer ice was predicted to all but disappear by mid-century. Also, parts of the high seas area, to the north of the

Chukchi Sea and Eastern Siberia, were already ice free by late summer. These areas are also shallower than those to the north of Europe.

Such speculation about a potential fishery in the CAO and in the high seas there brought with it the concern that distant water fishing fleets could show up in the region and that action was required to preempt such a development. The issue was raised at a number of conferences and also in the margins of the Food and Agriculture Organization (FAO) Committee of Fisheries in 2009.

The five coastal states bordering the CAO have discussed these matters for many years. The point of departure has been the existing global legal order for the oceans, including the high seas, based on the 1982 Law of the Sea Convention. Within the 200 nm exclusive economic zones coastal states have sovereign rights over the natural resources and the authority to manage fisheries. For the areas beyond the 200 nm, the high seas, the 1982 Convention and the 1995 UN Fish Stocks Agreement require states to cooperate on the management of fisheries. Today about 20 regional fisheries management organizations exist for the conservation and management of fisheries in the high seas areas of the world (Løbach et al. 2020). In 2008, the five Arctic coastal states confirmed their resolve in implementing the global framework provided by these instruments through the Ilulissat Declaration.[1]

In the North Atlantic the regional mechanisms for cooperation in fisheries management in the high seas include the Northeast Atlantic Fisheries Commission (NEAFC).[2] It has a mandate in the European sector of the Northeast Atlantic up to the North Pole. The International Council for the Exploration of the Sea (ICES)[3] assesses the status of the marine environment and the living marine resources in this region and provides scientific advice on the management of the fisheries in this region to coastal states and regional commissions.

AGREEMENT AMONG THE COASTAL STATES

In 2010, Norway invited the five Arctic coastal states to a meeting in Oslo to discuss questions regarding a potential future fishery in the high seas in the CAO. The outcome of the meeting was a request to the marine science institutes of the five countries to provide an assessment of the situation. A scientific meeting the following year concluded that there was little likelihood that fish stocks of commercial interest would expand into the CAO in the near future. It was also concluded that more research and monitoring was required in order to follow developments in the marine ecosystems in the High North.

1 For the text of the declaration see https://www.arctic-report.net/product/859/

2 For more on the NEAFC see https://www.neafc.org

3 For more on ICES and its role see https://www.ices.dk/Pages/default.aspx

Another meeting among the five coastal states in 2013 asked for further clarifications from the scientists, who met later that year. The scientists maintained the conclusions from their previous meetings and added that there was little probability of groundfish such as cod and haddock moving into the deep-sea areas of the CAO. Even if ice were to disappear, these areas are too deep for groundfish to thrive. But pelagic species such as polar cod *(Boreogadus saida)* could have some potential to expand northwards if conditions were right. Polar cod (called Arctic cod in North America) exists in the shelf areas around the entire CAO. Except for occasional fisheries in Russia, it is not exploited commercially.

Meeting in Nuuk in 2014 the five coastal states agreed to a declaration where they commit to abstain from fishing in the high seas area in the CAO in the absence of a mechanism to manage fisheries there, should they ever arise. The declaration also specified that the five countries would continue their scientific cooperation on these matters in a joint program on scientific research and monitoring. And it was stated that the five would work to expand the cooperation to include potential distant water fishing nations. The declaration was signed in Oslo in July 2015.[4]

NEGOTIATIONS ON AN EXPANDED AGREEMENT

At the initiative of the United States, an expanded process involving also Japan, the Republic of Korea, China, Iceland and the EU was initiated in late 2015. The main reason for including these states and the EU is that the law of the sea provides that in the absence of regulatory mechanisms, all states have a right to fish on the high seas. In order to prevent a potential unregulated fishery in the high seas in the CAO at some point in the future, it was deemed important to include potential distant water fishing entities.

Following the first round of talks in 2015, which mostly addressed the form and content of a future agreement among the five coastal states and the five newcomers, new rounds of talks followed in 2016 and 2017 in the United States, in Canada, in the Faroes and in Iceland. At the sixth round of talks in November 2018 in Washington DC agreement was reached on a legally binding instrument "Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean."[5] This expanded negotiation process was more complex than the previous ones among the five coastal states, partly because the number of parties was larger but also because the interests of those involved were more diverse and difficult to reconcile. Predictably, the five newcomers were more inclined towards potential future fisheries and facilitating that than the five coastal states were.

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[4] For the text of the declaration see https://www.regjeringen.no/globalassets/departementene/ud/vedlegg/folkerett/declaration-on-arctic-fisheries-16-july-2015.pdf

[5] The Chairman's summary of the agreement can be found at https://oceanconservancy.org/wp-content/uploads/2017/11/Chairmans-Statement-from-Washington-Meeting-2017.pdf

Photo 8.1: Norway's *Kronprins Haakon* ice-capable research vessel in action.

In parallel with the negotiations the scientific cooperation continued with annual meetings from 2015 onwards that included participation also from the newcomers. In Seattle in 2015 a comprehensive report on the status of knowledge on fish in the CAO was completed and a preliminary science plan was developed. The science plan was further developed at a meeting in Tromsø in 2016[6] and adopted following a science meeting in Ottawa in 2017.[7] At the latter meeting implementation of the science plan was also addressed and the final document contains a fairly detailed description of the future implementation of the science plan.[8]

THE 2018 AGREEMENT

The formal adoption of the Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean took place in Nuuk in October 2018. The specific purpose of the

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6 For details of meeting see https://archive.fisheries.noaa.gov/afsc/Arctic_fish_stocks_fourth_meeting/default.htm

7 For details of meeting see https://www.fisheries.noaa.gov/event/fifth-meeting-scientific-experts-fish-stocks-central-arctic-ocean

8 The Final Report of the meeting can be found at https://archive.afsc.noaa.gov/Arctic_fish_stocks_fifth_meeting/508_Documents/508_Final_report_of_the_5th_FiSCAO_meeting.pdf

agreement is just that – to prevent unregulated fishing from emerging in the high seas portion of the CAO. Article 2 of the agreement lays out the objective in more specific terms:

> The objective of this Agreement is to prevent unregulated fishing in the high seas portion of the Central Arctic Ocean through the application of precautionary conservation and management measures as part of a long-term strategy to safeguard healthy marine ecosystems and to ensure the conservation and sustainable use of fish stocks.[9]

In keeping with the approach of the 2015 declaration among the coastal states, the agreement stipulated that the parties—nine states and the EU—will abstain from letting their vessels fish or engage in fishing related activities in the high seas in the CAO for an initial 16 years following the entry into force of the agreement. Following that the ban on fishing remains in force in five-year increments as long as no party opposes it. The reasoning behind the initial 16-year ban is the need to be precautionary in accordance with the provisions of the 1995 UN Fish Stocks Agreement. Also, fishing is to be regulated on the basis of the best available scientific knowledge, and as of now our scientific knowledge of the marine ecosystems in the CAO is limited.

Another aspect of the agreement building on the 2015 declaration is the establishment of a Joint Program of Scientific Research and Monitoring. The fact that our scientific knowledge about the CAO is limited will likely make the development and implementation of this program a major part of the activity under the agreement for the foreseeable future. The implementation of the program is likely to be very costly, given the distances involved, the size of the CAO, and the costs of operating in ice-infested waters. But it is also likely to contribute significantly to enhancing our understanding of the marine ecosystems in the CAO.

The agreement underlines the importance of taking into account existing scientific work. In the Northeast Atlantic ICES is likely to play a key role, as it is the main provider of scientific advice to the coastal states as well as to NEAFC. ICES has had an Arctic Fisheries Working group for more than 50 years and is also developing ecosystem overviews for sub-Arctic seas.[10]

Still another element of the agreement is that it provides for a further process for development of regulatory mechanisms if fish should emerge in the high seas in the future and it is demonstrated that such resources could be exploited sustainably. If such a situation arises, the agreement will be the basis for further negotiations of regulatory arrangements such as those found in fully fledged regional fisheries management or-

[9] The text of the agreement can be found at https://www.dfo-mpo.gc.ca/international/agreement-accord-eng.htm

[10] For more on these overviews see http://ices.dk/advice/advisory-process/Pages/Ecosystem-overviews.aspx

ganizations, in accordance with the 1982 Law of the Sea Convention and the 1995 UN Fish Stocks Agreement. An important point in this respect is that the Northeast Atlantic Fisheries Commission already manages the areas beyond the 200 nm zones in the Northeast Atlantic up to the North Pole, including its regulatory area in the CAO. Here a number of NEAFC regulatory provisions already apply to the parties: Norway, the EU, Russia, and Denmark in respect of the Faroes and Greenland.

The agreement also has provisions relating to exploratory fisheries, new members, the relationship to non-parties, and so on. Decisions in matters of substance is by consensus (Balton 2019). For the agreement to enter into force, all 10 signatories have to ratify it. Russia was the first nation to ratify in February 2019, and since then all but two nations have ratified. At the time of writing (May 2020), only China and Iceland have yet to submit their instruments of ratification. Meanwhile a meeting of signatories was held in May 2019, and another scientific meeting was held in February 2020.

WHERE COULD A FUTURE FISHERY IN THE CAO TAKE PLACE?

There is a broad scientific consensus that the ice in the CAO will continue to diminish over the next decades, with most of the CAO being ice free in summer by mid-century. There is also broad agreement among marine scientists that stocks of living marine resources will continue to expand northwards, although the exact form and pace of such

Photo 8.2: Hauling of a trawl net in Norwegian waters.

development remains elusive. Also, impacts of increasing amounts of fresh water, ocean acidification, and inflows of Atlantic water make predictions difficult. It could however be safely predicted that a northwards expansion of fish stocks will first take place in the inflow shelf areas and not in the high seas. These areas are mostly inside the 200 nm zones of the coastal states. The five coastal states surrounding the CAO are all major fishing nations with modern and comprehensive fisheries management regimes. These domestic management regimes apply also in the CAO, to the 200 nm limit.

In the sub-Arctic seas, there are a number of fisheries that exploit transboundary fish stocks. In such cases there is already longstanding cooperation on management among the coastal states concerned. The perhaps most prominent example of this is the Norway-Russia bilateral fisheries commission, which was established in 1975 and meets annually to decide on total allowable quotas and other regulations for the fisheries on five shared fish stocks (cod, haddock, capelin, Greenland halibut and redfish).[11] This cooperation is based on longstanding cooperation between the marine science institutes in the two countries, which is embedded in the broader framework of the ICES, which provides the scientific advice for management to the Joint Fisheries Commission. Other bilateral cooperation mechanisms are not as developed as the Norway-Russia Cooperation, for the simple reason that there are few or no major fisheries to cooperate on—for now.

FROM A LARGER PERSPECTIVE…

From the vantage point of climate change the processes and the agreements described above are about adapting to the effects of climate change. An important point of departure in addressing this is that the international cooperation on fisheries management and the science underpinning it is more developed in the Northeast Atlantic than in the North Pacific part of the Arctic Ocean. In the Northeast Atlantic effective bilateral cooperation on fisheries management, a fully-fledged regional fisheries commission with a mandate up to the North Pole (NEAFC), and the perhaps most advanced international marine science advice mechanism on the planet (ICES) exist. For this reason, the perceived need for new institutional mechanisms may differ somewhat in the two regions.

From a more political perspective, the perhaps most important aspect of the negotiations described here and their outcomes is that the Arctic coastal states have demonstrated that the coastal responsibilities laid down in the global legal framework are assiduously implemented, thereby being on the precautionary side of developments. The particular responsibilities and interests of the five coastal states are recognized in the preamble of the 2018 Nuuk agreement.[12]

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11 For more on the Norway-Russia Fisheries Commission see https://www.jointfish.com/eng.html

12 "Recognizing the special responsibilities and special interests of the Central Arctic Ocean coastal states in relation to the conservation and sustainable management of fish stocks in the Central Arctic Ocean."

In the sub-Arctic seas where commercial fisheries exist, there are already well functioning management regimes at domestic, bilateral and regional levels of governance. Today this is in the marginal seas of the CAO, such as the Bering Sea and the Barents Sea. Reductions in sea ice and warmer waters could bring an expansion of fisheries into the CAO, but still inside the 200 nm zones of the coastal states. Commercial fisheries in the high seas outside the 200 nm zones do not seem very likely in the foreseeable future.

A comprehensive global framework exists for the management of living marine resources inside and outside EEZs. The added value of the 2018 agreement is the commitment of the 10 parties to prevent their own vessels from engaging in fishing in the high seas and in the commitment to increase their efforts in research and monitoring relating to the marine ecosystems in the High North. Also, the agreement discussed here represents a significant component of the remarkable development in pan-Arctic governance structures over the last decade. Starting in 2011, legally binding agreements have been concluded on search and rescue, oil spill prevention, international scientific cooperation, shipping (the Polar Code), and prevention of unregulated fishing.

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CHAPTER 9

LIGHTS ON IN THE ARCTIC OCEAN

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The sunlight impinging on the surface of the Earth does not spread homogeneously. Because our planet is a sphere, the beams of light that hit the slant surfaces at high latitudes, spread and *dilute* over larger surface areas. As a result, while the equator receives more than 300 watts per square meter on average over a year, the poles receive ca. 60 watts. Moreover, a large fraction (up to 85%) of sunlight impinging on Earth at high latitudes gets reflected back to space by snow, glacial ice and sea ice, so that only a small fraction is left for heating the surface and lower atmosphere. This is what fundamentally explains why the poles are cold, and without redistribution of some of the heat from lower latitudes through atmospheric and oceanic circulation they would be even colder.

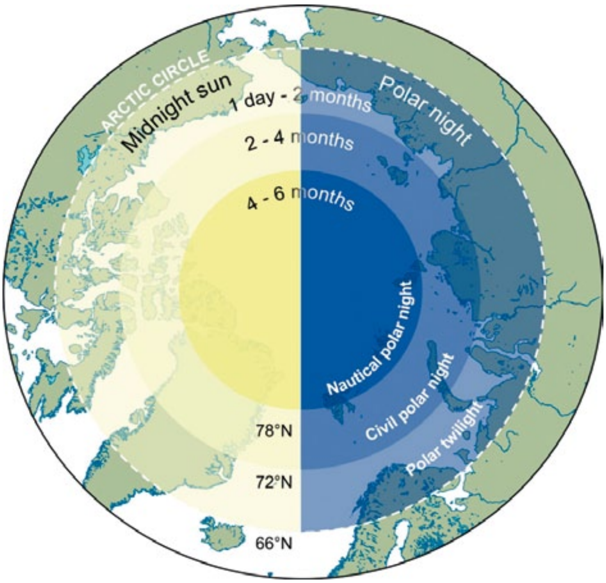
The coldness of high-latitude terrestrial ecosystems is what makes them deserts, not the lack of light as such. Indeed, the cold deserts found at high latitudes and low altitude, and at high altitudes and low latitudes, are very similar: rocky and icy landscapes with very low biomass and diversity. Low metabolic rates and the physiological challenges faced by living organisms at freezing temperatures explain the scarcity of life in such environments.

While Antarctica is the most polar emerged landmass, the Arctic Ocean is by far the most polar ocean. The former is a continent surrounded by the ocean, while the latter is an ocean that reaches the North Pole and is surrounded by continents. Because the Arctic Ocean is essentially the northern end of the Atlantic Ocean, it is filled in by seawater coming from the south that carries huge amounts of heat. While air temperature is around -35°C at the North Pole in January, the average temperature in the top 200 m of the Arctic Ocean is never less than -1.8 to 5°C, which makes it a genuine oasis where most of Arctic life is in fact found, or on which it is depending upon (many birds and some mammals). The main challenge for marine organisms living in the Arctic Ocean is not so much to sustain low temperatures, except in sea ice, but to get energy from the trophic network, which mostly originates from solar energy. Light, however, is precisely a rare resource in the Arctic Ocean that dictates in a very special manner the magnitude and rhythms of seasonal variations in biological production.

THE LIGHT CLIMATE IN ARCTIC

Celestial mechanics is the first reason why sunlight is so unusual beyond the polar circle in this most polar ocean. If earth's axis of rotation was perfectly perpendicular to the plane formed by the orbit of earth around the sun, for an observer sitting at the pole, the sun would run around over 360° *grazing* the horizon each day of the year. Because earth's axis of rotation is tilted by 23.5°, this scenario happens twice a year only, during the fall and spring equinoxes. During the summer and winter solstices, the sun rotates around the horizon at a constant elevation of 23.5 and -23.5° above the horizon, right in the middle of the midnight sun and polar night, respectively. At the polar circle during the summer solstice, the sun culminates south at 47° from the horizon, and grazes the horizon straight north at midnight. So, the sun cycle beyond the polar circle is anything but what we are used too at our medium and low latitudes: night/day cycle all year long, sunrise east, and sunset west.

Because of the prominent low sun elevation in Arctic, the path of photons through the atmosphere is longer so that they interact more with gas molecules and aerosol particles on their way to the earth surface, which further decreases the survival of photons. A significant fraction of the light reaches the ground as diffuse light from the sky rather



Map 9.1: Light conditions in the Arctic are highly variable and latitude dependent. The midnight sun and polar night last from 1 day to 6 months along concentric circles round the North Pole.

Photo 9.1: The low angle of the sun often creates a high reflectance over open waters.

Photo 9.2: The polar night. Nights in the High North are not only characterized by the absence of sunlight, but also by moonshine and spectacular sights like the Northern Lights.

than directly from the sun. And this is of course even truer under clouds, which are frequent if not permanent above open waters during summer and fall, contributing to further losses of photons.

In a nutshell, the polar night, the midnight sun, a generally low grazing sun and clouds are what characterize the light climate in the Arctic. But surprisingly enough, while light is most of the year absent or relatively low in the Arctic, the largest number of photons in a single day on earth is recorded during the summer solstice at the two poles.

LIFE AND THE LIGHT CLIMATE WITHIN THE ARCTIC OCEAN

In March, the whole Arctic Ocean above the polar circle is covered by sea ice, except for the Norwegian and Barents Seas. In September, the so-called first-year ice has melted over about 60% of its total March area, which corresponds to the Seasonal Ice Zone (SIZ). The remaining is multi-year ice, thicker, rougher and whiter. Pure water ice is essentially transparent. It neither absorbs nor scatters light significantly in the visible spectral range, compared with other natural media. When forming on a quiet lake, it is hardly distinguishable from water and looks black because lakes are photon traps.

Sea ice is very different. Because it contains multiple inclusions mostly formed or imprisoned during sea ice formation, including air, brines and precipitated salts, it is a highly heterogeneous optical medium with strong small-scale variations in the refractive indices. It looks white when drained and therefore containing more air (emerged part) and diffusing pale blue when saturated with liquid seawater (immerged part). What this appearance translates to is a high coefficient of light scattering. Rather than traveling straight through the medium, the photons change direction multiple times while interacting with it. As a result, a large fraction (around 55%) of the solar photons that impinge on bare sea ice are reflected back to the atmosphere. The remaining photons see their path through sea ice increased enormously because of scattering so that, despite the small absorption coefficient of the medium, most get absorbed and transformed into heat. Only a very small fraction of the incident photons finds its way to the ocean in the presence of bare sea ice (generally a few percent in the visible).

The attenuation of photons through the icepack is strongly magnified by the presence of snow, especially fresh snow. Optically speaking, fresh snow is made of air, and flakes with a myriad of facets that each reflects and refracts light. It scatters light much more than sea ice does. While aging, snow becomes denser (less air) with rounded snow grains (less facets), and therefore it scatters light to a lesser degree, although still more than sea ice. Typically, a fresh snow cover of 20–30 cm reflects up to 98% of incident photons in the visible, and absorbs more than 95% of the remaining, so that only about 0.1% of incident photons goes through.

Photo 9.3: The author holding an instrument designed for light measurements under sea ice. Here he exposes it to sky light for quality control of the sensors.

The daily irradiance amounts an average 70 mole photons per square meter and day during the summer solstice under clear sky between the polar circle and North Pole. Under typical cloudy conditions, this value drops down to 30–50 mole photons per square meter and day depending on the region. In ice-free areas of the Arctic Ocean, this is plenty for supporting the production of phytoplankton biomass at ocean surface. Indeed, an often-used threshold for net primary production, that accounts for usual losses due to respiration, grazing by zooplankton and other causes of mortality such as viral lysis, is 0.4 mole photons per square meter and day. However, in the presence of 1.5-m thick sea ice (average in Arctic) covered by more than 20 cm of fresh snow, at the bottom of sea ice, where so-called ice microalgae thrive, and in the top water column where phytoplankton is found, irradiance available for primary production crashes down to 0.3–0.5 mole photons per square meter and day at most (summer solstice), which makes primary production barely possible. During spring, the melting of the snow cover and the appearance of melt ponds on top of sea ice, besides the more frequent occurrence of leads, allow irradiance increasing to up to 3–15 mole photons per square meter and day, which is largely sufficient to support significant primary production under sea ice.

During winter solstice above the polar circle, the sun remains under the horizon all day. The polar night is characterized by very low light levels but in fact, not full darkness. Depending on how much the sun is situated below the horizon, various sources of light other than direct sunlight exist. Twilight is produced by the scattering of sun photons in the atmosphere while the sun stands 0 to 18° below the horizon, and irradiance drops up to a million times. Moonlight, starlight and zodiacal light are other dim but measurable sources of light during the polar night, that can be perceived, if not used for vision, by many living organisms. In the Arctic Ocean, however, these dim light sources get further dimmed by sea ice and overlaying snow.

At such low light levels, photosynthesis and primary production may seem impossible. The lowest known level that promotes net photosynthesis is 0.01 µmole photons m^{-2} s^{-1} (or 0.001 mole photons per square meter and day). So, obviously, net photosynthesis is indeed impossible in the Arctic Ocean during the polar night. But how early it can resume once the polar night has ended is unclear because of scarce observations during that period of the year.

Light detection and vision by living organisms are, however, possible even during the deep polar night under sea ice covered with fresh snow. The so-called civil twilight light levels amount to several tens of µmole photons per square meter and second at noon during the polar night. Full moonlight drops down to 1×10^{-3} µmole photons per square meter and second. Under sea ice and snow, those values may drop further by as much as three orders of magnitude. This is nevertheless still larger than the minimum light

Photo 9.4: Icebergs from Greenlandic glaciers, ice floes, and a thin layer of freshwater create fascinating light phenomena in the High North.

level perceivable by human vision, and several orders of magnitude larger than the detection limit of vision by many marine animals, including crustaceans and fishes. And indeed, Arctic zooplankton has been shown to be sensitive to such low light levels during the polar night, for instance synchronizing vertical migrations against the moonlight diel cycle and Northern Lights.

CURRENT CHANGES IN LIGHT AND KNOWN IMPACTS ON MARINE ECOSYSTEMS

For at least four decades the light-scape in the Arctic Ocean has been changing a lot, and because of modifications of the icescape it is expected to continue changing in the coming decades. The annual minimal extent of the icepack (September) has decreased by more than 40%, with a nearly 20% increase in the SIZ extent, where the duration of the ice-free period has increased by about 35 days on average over the last two decades. Both the snow cover and icepack thickness have decreased significantly. The warmer air temperatures that now prevail promote a more extensive formation of melt ponds during spring. The thinning icepack has become more mobile and prone to deformation, so that ridging, and the occurrence of leads have increased. All these changes in the icescape allow more sunlight to reach the bottom of sea ice and the upper water column. On the contrary, the current increase in cloudiness has lowered the amount of light reaching the ocean surface.

Several consequences of changes in the Arctic Ocean light-scape on marine ecosystems have already been documented. The most compelling ones relate to the phenology of microalgae. The phenology describes cyclic seasonal variations over a year. Not surprisingly, these photoautotrophic organisms respond promptly to variations in light, and this is reflected in seasonal variations of ice-algae and phytoplankton biomass. The peak in biomass observed each year during summer at any location in the Arctic Ocean (except at the highest latitudes) now takes place on average 15 days earlier compared with early 2000s , and up to 60 days in regions such as Baffin Bay. This so-called spring bloom, a curious expression when applied to the Arctic, takes place right before or after the summer sea ice breakup between late June and early September. Moreover, this event has become more intense and now also takes place at the highest latitudes where it previously used not to happen.

These changes are all related to recent modifications of sea ice dynamics. Sea ice melts earlier during late spring to early fall, and annually ice-free conditions are found at increasing latitudes. But the freeze-up date has also changed. It takes place on average 20 days later, which is partly responsible, together with more frequent fall storms, for the increased occurrence of phytoplankton fall blooms in the open water of the Arctic Ocean. The spring and fall blooms happen when both light and inorganic nutrients (especially nitrate) are sufficiently abundant. In spring, these conditions are met: 1) after the winter resupply of the upper water column by new nutrient from depth through

Photo 9.5: The low angle of the sun newly risen above the horizon creates spectacular colors on the snow cover.

vertical mixing (resulting from brine rejection during sea ice growth), and 2) after light rapidly increases because sea ice has become transparent enough or has melted. During fall, these conditions are met when thermal convection and wind stress promote vertical mixing of new nutrients, while the incident light level is still high enough and sea ice has not yet formed.

It is generally assumed that annual primary production in the Arctic Ocean is mostly constrained by nutrients, not light. The latter would play a major role in providing the pace to seasonal variations in primary production and biomass of microalgae. However, modulations of microalgae phenology controlled by light do have an impact on secondary production by pelagic and benthic organisms. Whether the spring bloom happens later as a brief and intense burst, or earlier as a smooth event spreading over a longer period makes a difference.

Pelagic grazers can only ingest the amount of microalgae biomass that is produced over a short period of time. What cannot be intercepted sinks to the bottom where it feeds the rich Arctic benthic fauna that is found on the wide continental shelfs that occupy half of the Arctic Ocean surface. When the bloom spans over a longer period, most of it gets intercepted by the pelagic food web to the detriment of benthic organisms. On the other hand, many secondary producers also follow their own seasonal biological rhythms by adapting either their ontogenic (life cycle) or physiological (diapause) capabilities. A match or mismatch between those rhythms in pelagic secondary producers, especially zooplankton, and microalgae phenology will affect the transfer of biomass to the benthos. Overall, changes in the microalgae phenology have an impact on the entire trophic network, from its composition of pelagic and benthic organisms, to the transfer of matter and energy through the water column and towards the bottom. Major modifications of the pelagic and benthic diversity, and changes in the coupling between the sea-ice, pelagic and benthic ecosystems have already been documented for the past few decades, notably in the Bering and Chukchi Seas where the modifications in the light climate played a role.

NEW WAYS OF STUDYING IMPACTS OF CHANGES IN THE LIGHT CLIMATE

The ongoing modifications of the light climate in the Arctic and the Arctic Ocean are, thus, driving profound changes in the dynamics of the marine ecosystems, including in biodiversity, trophic interactions and biogeochemical fluxes. But the full breadth of consequences now and in the future is hard to apprehend because of the lack of observations, which limits progress in knowledge and understanding of key basic phenomena, processes and changes. How is light actually propagating in the Arctic atmosphere, snow, sea ice and ocean? How is light related to the physical and chemical properties of these media, across various space and time scales? How are these properties changing and how are they affecting propagation of light and its use by living organisms? Who are the organisms that detect and use light? What is the tolerance and resilience of light-dependent or light sensitive organisms, and of trophic networks to changes in the light climate? How are biological rhythms affected?

Compared with terrestrial ecosystems, the ocean is a relatively homogeneous environment, at least optically wise, and quite similar to the atmosphere in that sense. Modelling light propagation in these media is relatively easy and prone to rather exact models and methods. Moreover, their apparent and inherent optical properties can actually be continuously measured, not only derived or estimated. On the contrary, snow and sea ice are extremely heterogeneous optical media. Within these *solid* media, it is difficult to collect good measurements of radiometric quantities such as radiance, and therefore difficult to obtain apparent optical properties such as the vertical attenuation coefficient. Moreover, because these media are strong scatterers of light, they prevent actual measurements of most inherent optical properties, such as the scattering coefficient. This makes the calculations of radiative transfer more difficult. Last but not least, the scales of variations in optical properties in these media go from mm to several km and even throughout regions, and from days to seasons and decades. To capture such a broad range of scales is a major challenge. It requires appropriate sensors, vehicles and sampling strategies.

In situ measurements of under-ice light levels are generally conducted at fix-point locations through boreholes, using underwater spectroradiometers. Such measurements are never repeated often enough to capture variations at scales of meters to tens of meters. To palliate this limitation, remotely operated vehicles (ROVs) are now used by two or three teams around the world to document the variability of under-ice irradiance at such scales. This represents a major improvement, but nevertheless does not allow capturing the entire variability, for instance due to permanent and transient leads.

At large scale, one can use satellites to estimate light transmittance through snow and sea ice. This has only recently been attempted. Despite a number of limitations, including the impossibility of using optical sensors in the presence of clouds, satellites provide a great means for documenting light variations at regional to basin and pan-Arctic scales. But satellites hardly see the details, i.e., variations under several kilometers. How to bridge meter-scale (ROV) and large-scale (satellite) measurements remains to be determined. The use of autonomous underwater vehicle (AUV) platforms may be part of the solution. Optical properties of sea ice and snow also vary much at very small scales (in the order of mm). This is the most difficult scale to sample because it requires penetrating the medium without altering it. Some progress has been made for snow, but for sea ice, the best approaches that have consisted in working on ice cores or in boreholes remain rudimentary.

Light is clearly a master variable of the Arctic Ocean environment. It is also an amazing vector of information used in all fields of science and engineering. Underwater optical sensors already exist for deriving the concentrations in seawater of chlorophyll, dissolved organic matter, suspended particles, oxygen, methane and nitrate. Most are now implemented on various autonomous sampling platforms, including profiling floats, gliders, and AUVs. High throughput imaging systems exist for quantifying and identifying zoo- and phytoplankton. Efforts are being conducted to miniaturize these systems. Maybe one day, we will be able to use them for exploring the sea ice interior habitat.

CONCLUDING REMARKS

To conclude, the light climate in the Arctic Ocean is changing. First of all, light is increasingly abundant at high latitudes in the ocean. The modifications in its seasonal variations affect the phenology of primary producers and consequently the dynamics of the entire trophic network and carbon flux. The extent of the consequences is unknown, and one can honestly ask, "Whither the Arctic Ocean?". Much more research on light needs to be done to understand its role and impacts in the Arctic. This requires not only new tools, experimental approaches and annual and spatial coverage, but also a change in attitude among the research nations of the Northern Hemisphere towards a pan-Arctic comprehension.

CHAPTER 10

MELTING ICE AND CLIMATE CHANGE: HOW WILL OUR FUTURE BE?

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INTRODUCTION

The ice sheets, ice caps and glaciers in the Arctic are melting and this will influence the life of everyone from the people of the Arctic to everyone living close to the ocean around the world. I find that improving our knowledge on how fast the ice is melting and also on how sea level will rise regionally is vitally urgent and important in order to prepare for our future. In addition, the melting ice and the warming ocean strongly influence living conditions in the Arctic as fisheries change, harbors become open year-round and both terrestrial and ocean areas become open for exploration of oil and minerals. My research field focuses mainly on understanding how climate has changed in the past and how the Greenland ice sheet has changed volume in the past. We see that there have been big and abrupt changes in the past, even without human influence. This knowledge is an important tool in understanding how the climate and ice in the Arctic is changing now and shows that the climate system can react strongly to changes. We need to know what we can expect in the future.

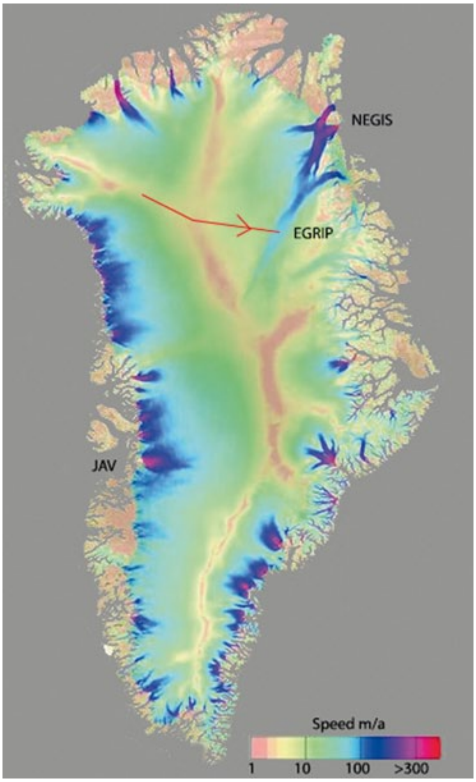
THE GREENLAND ICE SHEET

The Greenland ice sheet is the second largest body of ice on Earth. The volume is close to 3 million cubic kilometers of ice and if all the ice melted this volume would be equivalent to 7 m of global sea-level rise. While Antarctica is ten times larger it is the Arctic that is presently experiencing the strongest increase in temperature and thus it is the ice sheet, ice caps and glaciers in the Arctic that is by far the dominant component of melting ice. The present global mean sea-level rise is 3.5 mm each year. Of this the Arctic ice contributes 1.5 mm each year. The melt of ice from the Greenland ice sheet is mainly from a) marginal melt and b) discharge of ice from the ice streams[1] surround-

[1] A fast-moving ice or ice stream is a region of an ice sheet that moves significantly faster than the surrounding ice. Ice streams are a type of glacier.

ing Greenland. The contribution from the two sources are similar in size. The warming temperatures cause more melt along the margin of the ice sheet both by melting more ice near the coast, but also by increasing the area with melt at higher elevations on the ice sheet.

The ice streams are seen as areas with high surface velocities on the Greenland map (map 10.1). There are ice streams all around Greenland but a few stand out. The glacier Jakobshavn Isbræ (JAV) on the west coast of Greenland near Illulisat with a surface velocity of 14 km per year drains 70–80 GT (or 80–90 cubic kilometers) of ice each year. This represents 0.2 mm of sea-level rise just by itself. The Northeast Greenland Ice Stream (NEGIS) covers the largest area and discharges 30 GT each year. Most of the ice streams surrounding Greenland have accelerated since year 2000 and are thus discharging more ice into the sea. As an example the Jakobshavn Isbræ doubled its speed from 7 km per year before 2002 to 14 km per year after 2004. The changing velocities are believed to be connected to the warming of the ocean, the increased surface



Map 10.1: Surface velocities on the Greenland ice sheet: https://nsidc.org/data/NSIDC-0670/versions/1 (modified by D. Dahl-Jensen).

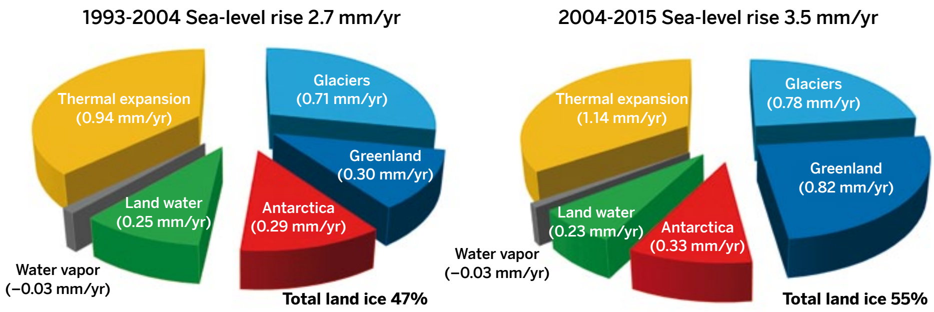


Figure 10.1: Pie chart of contributions to sea-level rise: https://sites.google.com/site/ireland-climatechange/WMO%20Statement%20on%20the%20State%20of%20the%20Global%20Climate%20in%202017%20Sea%20Level%20Rise%2002.jpg

meltwater penetrating to the bed under the ice streams and the increase of snowfall on the top and center part of the ice sheet. We are not fully capable of modelling the ice streams and their changing velocities due to our lack of understanding of the processes involved. The various sources of sea-level rise are illustrated in figure 10.1. Take note of the significance of thermal expansion and the increasing contribution of the Greenland ice cap to sea-level rise.

DRILLING DEEP ICE CORES

I have been involved in the drilling of deep ice cores through the Greenland ice sheet from the top to the bedrock, 2,500–3,100 m below the surface (photo 10.1). The ice cores contain layers on layers of annual snowfall becoming older and older with depth and can thus be used to learn about the past climate. Near the bedrock the ice layers are more than 150,000 years old. The projects are international and involve researchers from Japan, China, US, Australia, New Zealand and Europe. We establish camps that can house around 30 scientists during the summer months on very cold and remote sites on the Greenland ice sheet. At present we are drilling the EGRIP (East Greenland Ice-core Project) ice core in the center of the NEGIS ice stream both to understand the past climate but also to learn how an ice stream flows as they are so important and badly understood contributors to sea-level rise. In 2015 we moved the camp 440 km from the previous camp to EGRIP and Photo 10.1 shows the 55-ton heavy main building—the Dome on skis—being pulled over the ice sheet at a speed of 10 km per hour. The ice core drilling and the first measurements on the ice cores are done in subsurface snow trenches where the temperatures are constantly low and not influenced by the surface weather. In these trenches international teams measure ice and climate properties and cut samples for further climate analysis in more than 100 laboratories around the World.

Photo 10.1: Images from the deep ice core drilling program. *Top left*, cutting an ice core; *top right*, moving the Dome 440 km over the Greenland ice sheet to EGRIP in 2015; *bottom*, the subsurface science trench.

ICE CORES AND CLIMATE

From measurements of the stable water isotopes[2] and the greenhouse gases in the trapped bubbles of old atmospheric air enclosed in the ice we learn that during the last glacial period from 115,000 to 11,700 years ago we experienced 25 events of very rapid warming of the climate over Greenland. During each of them, atmospheric temperatures increased by 7ºC to 15ºC over just 100 years, then cooled down slowly over a few thousand years. These events are called Dansgaard-Oesschger events named after professors in ice core related research from Copenhagen and Bern. They are specially related to the glacial climate and are not at all caused by human activities. They were, however, followed by global sea-level rise of 5–10 m showing strong loss of mass from the glacial ice sheets over Greenland, Antarctica, North America and Northern Europe. Increases and decreases in sea level are thus common and a natural component of land-sea interactions. In addition, from 130,000 to 115,000 years ago under the 15,000-year last warm interglacial period,

[2] The stable isotopes of hydrogen and oxygen have a long history of use in hydrology and paleoclimatology. They are measured to evaluate the age and origins of ice.

there was a period of 5,000 years where the temperatures became very warm and our results show that the temperatures were 5°C warmer than present over the Arctic in this period. Investigations of the ice cores show that the surface was lower and the ice sheet lost around 20% of its volume corresponding to 2 m of global mean sea-level rise. During the last warm interglacial period sea level was 5–9 m higher than at present.

OUR FUTURE?

The knowledge gained from using ice cores to understand the climate of the past has taught us lessons about the behavior of the climate system—how warming of the system leads to sea-level rise. It is natural for the climate system to change, to wax and wane between glacial and interglacial periods and to have rapid unstable events of a duration of 2,000 years during the glacial. The present warming is clearly caused by human activities leading to increased concentrations of greenhouse gases in the atmosphere. All evidence from the past shows that increasing temperatures in the Arctic cause ice to melt resulting in increased sea levels. In less than a hundred years atmospheric temperatures in the Arctic will very likely be 5°C warmer than those we experienced in the period 1950–80, i.e., before the largest contribution of man-made warming started. This brings us to the same temperatures we had during the last interglacial period 130,000 years ago. We should thus expect Greenland to lose 20% of its volume and sea level to increase 5–9 m. As humanity unavoidably has to adapt to sea-level rise an important question is—how fast will it happen? Also this question is challenging to answer because we lack sufficient time resolution in the observations of sea-level rise from the paleodata. Also, the models have uncertainties that are of the same order as the sea-level rises themselves even for the year 2100 predictions.

SEA-LEVEL RISE

This uncertainty on the sea-level predictions is worrying. How do we prepare for the inescapable future of sea-level rise? The Arctic sea-level rise will in general be less than the global average because large land areas are still lifting after the termination of the last glacial period 11,700 years ago. Also, the Arctic ice that is melting right now introduces the largest sea-level rises in the southern hemisphere. Understanding ice flows and especially the behavior of ice streams is urgently needed to improve predictions of ice loss and thus sea-level rise.

For me it is clear that the best strategy to avoid serious increases in sea level is to reduce the emissions of greenhouse gases globally. This would reduce the increase of atmospheric temperature and thus the increase in melting ice. It is a global responsibility to reduce emissions and—while the climate changes are strongest in the Arctic and it is thus exposed to humanity's greatest changes in living conditions—sea-level rise is something that impacts everyone on Earth. Mostly outside the Arctic realm. I hope we can stand together and change our way of living in order to succeed in reducing emissions of greenhouse gases on a global level.

WISHES FOR THE FUTURE

My research has focused on understanding the past climate from ice core measurements mainly from the Greenland ice sheet. Motivated by present climate change in the Arctic my research has in recent years turned more towards present climate changes, the melting ice and the impact on people living in the North. The ice streams with the discharge of fresh water into the ocean are very important for fisheries. The fresh water with the nutrients from the melting ice is an important source for primary production. Knowledge of the fresh water discharge in the future is thus crucial for the communities in the North. But while we observe in general, from satellite and direct measurements, that most ice stream are speeding up as the ocean warms we also see that the Jakobshavn Isbræ has slowed down in very recent years. We really need to focus on understanding the ice steams as they are so important for both communities and sea-level rise globally. I hope that the research at the EGRIP site on the NEGIS ice stream will help us improve our understanding of ice streams. In this way, I hope to contribute to our future. I consider it urgent to build Inuit-managed research programs. In my view, Northern Baffin Bay between Canada and Greenland, where it is intended to form the first Inuit-managed area in Pikialasorsuaq, is an obvious place to enhance the observations of ice streams. The changing amount of fresh water delivered to the ocean strongly alters ecosystems and thus impacts the living conditions in the area. I hope to be able to contribute to such programs which will benefit both local communities as global sea level predictions important for all on our Globe living close to the sea.

CHAPTER 11

LOSING THE ARCTIC

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LOOKING NORTHWARD

The Polar Regions have long held humanity's fascination. Of our planet's two poles, the Arctic is particularly unique because it shares a hemisphere with the majority of Earth's landmass, yet itself consists almost entirely of ocean. This means that for both early explorers and modern scientists alike, there have been no emergency structures, gear caches or landing strips. For the past several centuries and to this day, nearly all human movement in the Arctic has been by boat or over frozen sea ice. Early explorers, like Franklin and Nansen, dispatched accounts of an inhospitable, endless frozen expanse with ship-crushing sea ice and a relentless polar winter that claims all but the absolutely best prepared during the never-ending winter night. This imagery is nested into our minds from a young age, but that Arctic Ocean is rapidly disappearing.

In 2016, a family of seven, including five children, sailed the Northwest Passage in a 15 m sailboat. In 2017, a non-ice reinforced Russian tanker traveled the Northern Sea Route along the coast of Siberia from Norway to South Korea for the first time in history. Although the entire Earth is experiencing climate-related changes at an alarming rate, nowhere is the change more striking than in the Arctic Ocean and its surrounding coastlines. For the past twenty-five years, every second or third year has marked a new record low in sea ice extent, age and thickness, causing an ice-free summer Arctic Ocean to rapidly transition from a hypothetical scenario into a new reality. The Arctic Ocean is entering a new chapter of its existence and it is up to us to document and weigh trying to mitigate it.

A NEW NORMAL IS FAST APPROACHING

Humans will survive on a planet where words like *polar* and *Arctic* lose their current meaning, but what will be the cost to ecosystems, biodiversity, human life, the global

Photo 11.1: Fisheries research vessel *Lance* samples the ice-covered waters around Svalbard.

economy and the preservation of our familiar world, the world we became highly successful in? Is the Arctic merely a decorative attraction on our planet? An endearing subject of a documentary we watch after work? Or is it an unseen power plant, such as those we use to feed our electric appliances, which we do not think about as we go about our day, but will immediately leave us handicapped if the lines are cut?

Our scientific understanding of these questions can be constrained by two components: evidence, in the form of measured and predicted quantities; and confidence, in terms of a consensus story corroborated across a myriad of varied approaches to quantify our earth. Despite several decades of dedicated research in the Arctic by dozens of nations, both are essentially in their infancy. The human ability to reach a deep understanding of the Arctic Ocean is obstructed by several key factors. First, its remoteness from civilization. An Arctic expedition to collect scientifically meaningful data in such a remote, inhospitable environment requires enormous budgets, accessible only to governments. Successful data collection is made even more difficult by the limited window of sampling that is only possible during two months in polar summer, when sea ice is at its lowest coverage and polar night has not yet set in. As a result, nine tenths of what we know about the Arctic Ocean is based on a brief glimpse into the yearly cycle, with the winter still being a blank page for nearly all aspects of marine science in the High Arctic Ocean.

A DIVIDED ARCTIC

Jurisdiction over the Arctic is shared by a number of different nations, and its broader impacts may be felt by the whole world. However, there is no global governance over the Arctic. The countries that share stewardship of the Arctic each have their own interests and claims. These are regulated by the United Nations Convention on the Law of the Sea (UNCLOS), but there are no international regulations designed specifically for the Arctic, in contrast with most other marine territories shared by different nations. Yet the sectorial and political boundaries do not exist for winds, ocean currents, and flora and fauna that inhabit the region. Outside of open source satellite data, science in the Arctic Ocean is financed and carried out by individual research initiatives, with only a handful of them being truly international and multi-governmental. The 2007–2008 International Polar Year was a notable exception, with dozens of nations working simultaneously across the Arctic. However, the immense dataset generated during this time was never synthesized on an international level. The ongoing Multidisciplinary drifting Observatory for the Study of Arctic Climate, MOSAiC, expedition is another example of a bold, ambitious effort to bring the world together with the common goal of expanding our knowledge of the Arctic Ocean. Yet the vast majority of past and present studies are sectorial, restricted in space by political jurisdictions and with very limited efforts to connect them together or ensure they are telling a compatible narrative.

Photo 11.2: Sea-ice algae coat the underside of first-year ice flows in the Arctic.

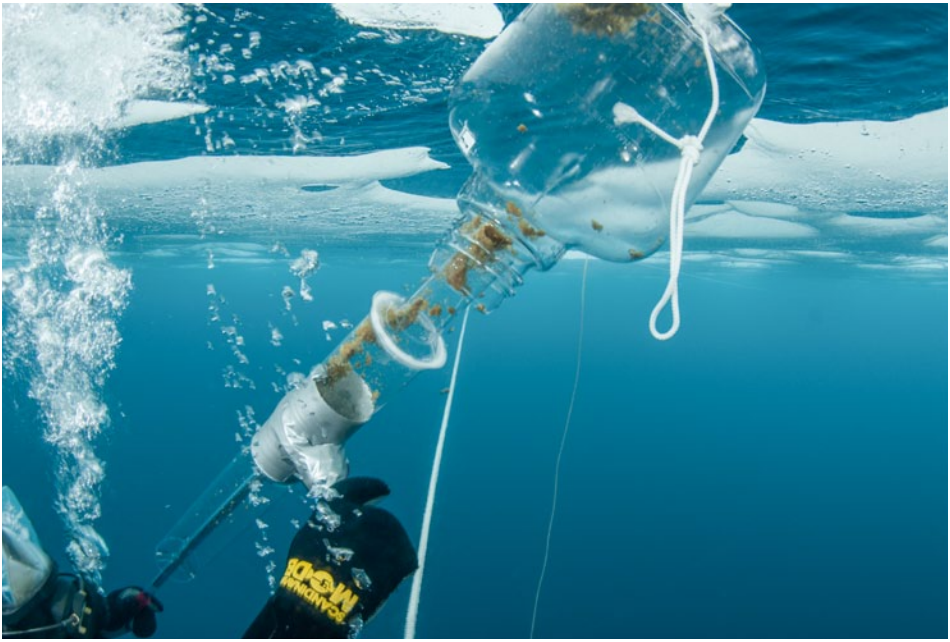

Photo 11.3: Research divers collect algae from under the surface of the ice.

Reasons for this include the difficulty of obtaining permits for sampling across political borders or of funding larger-scope projects, as well as simply different traditions for conducting research in different national bodies. This includes different approaches to sampling, processing and storing data, as well as publishing and disseminating the results and raw data. Another factor is the traditionally enormous gap between science and policy, a fault that is shared by both entities. In order for us to understand the whole Arctic as a single Mediterranean-type system, scientists must work together with politicians to initiate policies that would make the sharing of financial burdens of science more seamless and free up the movement of vessels in the Arctic. Funding bodies must encourage pan-Arctic comparative studies, with a large number of international partners, and make sure the data obtained becomes publicly accessible. Fixed observatories, like the Distributed Biological Observatory (see https://www.pmel.noaa.gov/dbo/) can encourage individual research initiatives working in the same region, spanning all disciplines and nationalities, to contribute to a common data pool. Another important, albeit more challenging, objective is to overcome the strong traditions of conducting science by most national scientific communities and to standardize methods of sampling and data analysis.

Historically, collaborative work in the Arctic has been highly dependent on the political climate. A prime example is the Bering and Chukchi Sea area, an important international fishing ground and a region of high consequence for the entire Arctic Ocean. This region also represents the Arctic's only inflow gateway from the North Pacific. The Russian-US border divides these seas down the middle and, due to historical hostility between the two nations, the vast majority of studies have been restricted to either one or the other side of the border, with little communication between the scientific communities on either side. On the opposite side of the Arctic, the Barents Sea, an equally important inflow region from the Atlantic Ocean, is split between Russia and Norway, which have a long history of high-quality collaborative scientific work that is still ongoing, resulting from an overall amiable relationship, and a mutual interest in exploiting and protecting the available natural resources.

LIFE BENEATH THE DISSAPEARING ICE

Despite all of these methodological, logistical, political and cultural difficulties, several aspects of the changing Arctic are known with certainty. Within the two-month polar summer window scientists have been extremely productive at obtaining direct observations of the meteorology, physics, chemistry, geology and biology of the Arctic Ocean, complemented by year round satellite data, as well as limited year-round observations obtained by platforms such as the Russian Drifting Stations. Some of this knowledge is summarized below.

Photo 11.4: Aggregates of sea-ice algae make a rich meal for the numerous ice-associated animals, like these *Apherusa* amphipods.

Between 1979 and 2018 Arctic sea ice extent has decreased during all months of the year, changes that are likely unprecedented for at least the last 1,000 years. The proportion of ice that has survived longer than one year without melting, a fundamental feature governing Arctic Ocean dynamics, has declined by approximately 90% since 1980. Most models agree that the vast majority of the Arctic Ocean will only contain one-year or seasonal ice within 5 to 30 years (IPCC 2019). These dramatic changes are of quantities that are easily measured from satellites but only reveal information present at the surface. Underneath the Arctic skin is a complex and fragile marine ecosystem. If the extreme changes at the surface are a bellwether for the unknown below, Arctic ecosystems may be facing more upheaval than we can currently imagine.

Shrinking sea-ice cover means that more light can reach the ocean surface for photosynthesis, and satellite images showing algae blooms suggest an increase in primary production across most of the Arctic (Arrigo and van Dijken 2015). An earlier ice retreat and a later freeze-up amounts to a longer growing season, and some parts of the Arctic have now been observed to have not one annual bloom, but two, similar to lower latitude systems (Waga and Hirawake 2020).

In other areas of the Arctic, however, it is nutrients such as nitrogen, and not light, which limits plant growth. Ice melt creates a fresh, less dense layer of water at the ocean surface, which decreases mixing and prevents nutrients from the deeper ocean reaching the upper layers, rendering the newly available light meaningless for the surface-dwelling algae (Polyakov et al. 2020). Increasing water temperatures may also shift microalgal communities from large, nutrient-rich varieties to small species that are much less palatable for many resident grazers (Coello-Camba et al. 2014). Warmer water also increases the overall respiration—algal cells, just like land plants, not only fix CO_2 but also respire it—and it is predicted that with a 5ºC increase in water temperature within the Arctic microbial communities the balance can shift from an overall carbon sink to a carbon source (Cai et al. 2010).

Satellite records also do not account for algae that live directly in and under the ice. Although it is likely that these constitute only a small proportion of total production, they are an important food source for animals that live in direct connection with the ice. They can also benefit animals living on the seafloor, as ice algae can form dense mats which then sink quickly when the ice melts (Wiedmann et al 2020). Therefore, although most observations and models agree on an overall increase in algal biomass over the past and coming decades, our very patchy in-situ knowledge of pelagic and ice production, make it difficult to predict with certainty the extent and quality of the changes in primary production that will happen in a future Arctic Ocean.

Further up the food chain, there is even more uncertainty. The zooplankton, small animals that drift with the currents, capitalize on the aforementioned brief, but intense, mi-

Photo 11.5: The polar cod, *Boreogadus saida*, finds shelter underneath the ice. Polar cod is a keystone species in the Arctic, serving as the main food source for birds and marine mammals.

croscopic algal blooms, and package them into fat-rich, rice-sized morsels that make up the main menu of nearly all larger animals that live in the Arctic, including fish, birds and marine mammals. Many of these species, as well as their predators, are uniquely adapted to the seasonal cycles in the Arctic, timing their reproduction to make the most of the brief spurts of growth that happen every year once the ice retreats (Kosobokova 2012).

Many of them also rely on the sea ice for food, platform and shelter. While a longer growing season and increasing algal biomass may give them more opportunity to feed, the shift to more boreal conditions will also inevitably be accompanied by sub-Arctic species moving northward, potentially threatening the generally larger, slow-growing resident species by predating on them or outcompeting them for resources. Shifts from Arctic to boreal communities, including those containing commercially important species like cod and capelin, along with their prey, have already been observed in parts of the Arctic, particularly in regions heavily influenced by inflow from the North Atlantic and Pacific Oceans, such as the Barents and Bering Seas. Some biodiversity loss is expected among the species directly connected to, or heavily reliant on, sea ice and those that are particularly sensitive to perturbations in the environment, such as ice seals or polar bears. Other organisms that currently inhabit the Arctic are opportunistic and may adapt successfully to the changing environment.

One aspect of the Arctic that will not change within a changing climate is the amount of sunlight it receives during an annual cycle. While winter studies are still scarce, there is rapidly emerging evidence that polar night ecology is much more complex than merely being a period of complete dormancy for ecosystems (Berge et al. 2015). Most Arctic animals rely on stores of fat to survive the winter months, but there is increasing evidence that organisms across all levels of the food chain are able to maintain levels of activity far higher than would be predicted by sun-driven primary production estimates, likely exploiting degrading leftover material from the summer, as well as microbial and chemically synthesized (non-sun driven) production. The ability to survive without sunlight-driven production for 3–6 months during a year, either through internal fat stores or the ability to exploit available resources, will largely determine which species can successfully *invade* the Arctic and how far into the Arctic they can reach. For these reasons, the deep Arctic basin and its highest latitude margins, will likely remain an unsuitable habitat for most sub-Arctic organisms.

SO WHITHER THE ARCTIC OCEAN?

While changes are imminent, their full scope and directions are difficult to predict with certainty. At its marginal seas, the Arctic Ocean will likely resemble more and more its boreal counterparts, while the sun's movement, for better or for worse unaffected by human activity, for the foreseeable future will ensure that the highest latitudes continue to experience Arctic conditions at least during the winter months, keeping out both human and non-human invaders from the south. As the accessibility of the Arctic Ocean increases, it will become more economically valuable, but also more vulnerable to human impact.

The future Arctic will bring new opportunities, and together with them new responsibilities. All of the issues facing other parts of the world—pollution, contamination with chemicals, oil spills—will migrate along with people as industry, fisheries, tourism and shipping move farther into these remote regions. During the winter polar night ship traffic brings in artificial light, which has been shown to affect behavior of organisms up to depths of 200 m. Our presence will place an additional toll on the Arctic ecosystem, already pushed to its limit by climate change. As the Arctic is becoming more and more accessible to non-ice specialized vessels, these new prospects should be used not just to increase industry and shipping, but to double our science efforts in a coordinated, international way. Pan-governmental structures are needed to sew together fragmented knowledge and forge an efficient path forward, both in quantifying the significance of the Arctic and managing its evolution. It is not clear that *Arctic* will hold the same meaning for our grandchildren as it does to us now, but we must do our part to at the very least preserve the knowledge of the Arctic that once was.

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CHAPTER 12

THE FUTURE ARCTIC OCEAN: MOVING TOWARDS A NEW STATE OR HEADING BACK TO THE PAST?

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The Arctic Ocean is large and the term encompasses many regions. Here, the Arctic Ocean mainly comprises marine ecosystems located alongside the northern coast of Russia and adjacent areas.

The Arctic has great importance for Russia. Approximately 20% of Russian territory is located north of the Arctic Circle. The Russian shoreline includes six Arctic Seas: the Barents, White, Kara, Laptev, Eastern Siberian and Chukchi Seas. The length of Russian Arctic coastline is approximately 22,600 km out of 38,700 km or 45,300 km (depending on the Arctic Ocean definition) of all countries adjacent to the Arctic Ocean (e.g., Bartsits 2000; Kozlov, Gudovskikh, and Kuznetsov 2010; Joudro 2015). Considering the sectoral division of the Arctic, the total area of the Russian polar sector located north of the Arctic Circle is 7 million km^2 (marine area only), or 46% of the Arctic Ocean area (Bezrukov 2015).

The history of Russian investigation and development of the Arctic spans several centuries. The names of Russian pioneers and investigators are reflected in a variety of geographical names—e.g., the Laptev Sea, Capes Dezhnev and Chelyuskin, the Sannikov, Dmitry Laptev and Vilkitsky Straits and Ushakov and Zhokhov Islands and the Arctic Institute Islands. The city of Murmansk, where I am based and work, was founded in 1916 and subsequently became the capital of Arctic Russia. It is the largest city beyond the Arctic Circle, the base of the huge fishing fleet as well as of scientific institutes which conduct research on the Arctic marine ecosystems and fisheries: the Polar Research Institute of Marine Fisheries and Oceanography (PINRO; now Polar Branch of VNIRO) and the Murmansk Marine Biological Institute (MMBI). Moreover, it should be mentioned that the predecessor of PINRO was founded by the decree of Vladimir Lenin in 1921 during the hard years of the Civil War in Russia.

In this regard, it is obvious that the Arctic is of great importance for Russia and that Russia has significant responsibility for the Arctic. Therefore, Russia and Russian science

Photo 12.1: The port of Murmansk in early winter.

pay constant and close attention to the Arctic. Currently, significant climate change is observed on our planet, including in the last two decades (since the late-1990s) with significant warming in the seas of the North Atlantic and the Arctic Ocean, in particular in the Barents and Kara Seas. According to some scientists and public opinion, this can lead to strongly negative consequences for the Arctic Ocean—a complete loss of ice cover and irreversible changes in the Arctic marine communities and extinction of many, if not all, Arctic marine animals. Since I have more than 30 years of research experience working in Arctic marine ecosystems, I would like to express my considerations on this issue and ask if we are moving into a new state or heading back into the old state?

THE PRESENT

To discuss what is the future of the Arctic Ocean and its marine ecosystems, we must first ask if we fully understand how the Arctic Ocean functions?

Do we know exactly what the Arctic Ocean was like in previous years, decades, centuries and millennia? In fact, Arctic scientific research has a fairly short history, a maximum of 150–200 years. Targeted, large-scale research in the Arctic Ocean has been carried out only since the 1920–1930s, and more precisely since the 1950s. Besides, the imple-

Photo 12.2: Investigations of the Arctic marine ecosystem in Russian research surveys. *Left,* PINRO scientist Vladimir Chernov conducts biological analysis of cod; *right,* PINRO scientists Ilya Dolgolenko *(left)* and Aleksandr Kuzmichiov *(right)* display a large cod from a recent catch.

mentation of marine research was greatly complicated due to a very short period of open water after the retreat of the ice edge, often no more than 1–3 months. The most intensive studies of the Arctic Ocean took place in the last 20 years due to the decrease in ice cover and the possibility of using scientific vessels for longer summer periods. Therefore, we should understand that most of our knowledge on the Arctic Ocean refers mainly to the modern period of 50-70 years.

Do we know how the Arctic Ocean functions now? I believe this question can be answered generally "no", but for some areas (like the Barents and White Seas) "yes". Many biological patterns of individual species' distribution, the current state and dynamics of marine species' populations, the relationships between phytoplankton, zooplankton, benthos, fish, sea birds and marine mammals have been revealed in recent years by both Western and Russian scientists (Institute of oceanology, PINRO and MMBI). Nevertheless, many questions remain: for example, what species inhabit the Arctic Ocean (scientists still regularly reveal new species of marine organisms that have not previously been registered in the Arctic, and also describe scientifically new species, for example, several new species of snailfish in the Kara Sea)? Is there one single population of the most abundant arctic fish—polar cod *(Boreogadus saida)*—or several populations in various Arctic Seas? What are the migration patterns of marine Arctic organisms? For example, how is it that snow crab, a native species of the North Pacific and northern Greenland, are now found in the Barents and Kara Seas? What are the biogeographical connections between different regions of the Arctic Ocean?

Can we predict what the Arctic Ocean will be like in 10, 50, 100 or 200 years? In my view and despite the numerous climate and other models, the accuracy of such forecasts remains controversial. In addition, only possible climate, ice or oceanographic conditions are normally forecasted in such models, but not the state of biological communities. This is mainly due to rather poor knowledge of the mechanisms of Arctic Ocean ecosystems and the interactions of biological communities with the environment and within biota. Nevertheless, we must apply time and dedication to study these questions and try to predict possible changes in the Arctic Ocean.

THE FUTURE: WHAT IS THE NEW ARCTIC OCEAN?

What will the *new Arctic Ocean* be like? Recent studies have shown that there has been a shift in the warm-water boreal fish species. They expanded north- and eastwards and their abundance increased during the last two decades in the Barents Sea. At the same time, the distribution area of cold-water Arctic fish species declined, with a simultaneous decrease in abundance. This suggests that the Arctic fish species are being actively and quickly replaced by boreal ones in the Barents Sea, a so-called *borealization* of fish communities. Similar processes are being seen within invertebrates, plankton and benthos. Theoretically, two development scenarios in the Arctic Ocean situation seem possible.

The first scenario is the most unfavorable—a further increase in air and water temperature, a crucial or complete disappearance of ice and a warming in the marginal seas of the Arctic Ocean (excluding its central deep-water part). This can lead to a reduction and further complete loss of the habitat for coastal and shelf species and, consequently, to a decrease of the distribution area and theoretically (in extreme cases) complete extinction of such Arctic marine organisms.

The second scenario holds out some hopes—further warming for some time, and then cooling that will result in the return of marine ecosystems and their inhabitants to their former state, corresponding to the state of the 1950s–1990s (cool period) or 2000s–2010s (warm period, but without extreme conditions for Arctic species). In this case Arctic habitats remain and Arctic marine organisms can survive longer periods of warming. After a new cooling period their original habitat region can be reoccupied.

IS CLIMATE CHANGE REVERSIBLE AND CYCLICAL OR NOT?

The key question for the future of the Arctic is the following: how strong anthropogenic warming is and can it result in irreversible climate warming and continued warming of the Arctic Ocean until a stable state is reached? Or is climate change cyclical and the current warming period will inevitably give way to a cooling period sooner or later? The first answer to this question may lead to an almost complete and final loss of the Arctic

Photo 12.3: Ice floes in the Barents Sea.

marine ecosystems (only some Arctic relict species can survive in some places) and their replacement by boreal-type ecosystems, at least in marginal Arctic Seas. The second option gives hope for the conservation and restoration of the Arctic marine ecosystems.

Some scientists believe that warming will continue and warming is already an irreversible phenomenon—inter alia due to intense anthropogenic warming—and any possible further cooling will be warmer than cooling periods in the past. Other scientists believe that we are currently at the peak of the warming process and after some time a natural cooling period will take over. I tend to believe that warming will eventually give way to cooling probably during the next 5–10–20–50 years. We are already seeing some warming events beginning in the Barents Sea. For me personally this view is supported by the publications of Soviet scientists (G.V. Boldovsky, L.S. Berg, M.S. Zernov, E.V. Chumaevskaya-Svetovidova), which noted the occurrence of new warm-water fish species in the Barents Sea in the warm period of 1935–39, such as blue whiting, Norway pout, Atlantic saury, mackerel and others. After the cold period of the 1950s–80s, these species have been registered again in the Barents Sea as "new species" since the late 1990s. Besides, it is well known that periods of warming and cooling have already been recorded in the history of Europe (e.g., the Medieval Climate Optimum, 950–1250) and the Little Ice Age (approximately 1300 to early 20th century). There is no reason to believe that periods of natural warming and cooling will not repeat in the future, even under anthropogenic warming conditions.

WHAT IS THE MOST INFLUENTIAL FOR THE ARCTIC OCEAN: NATURAL CLIMATE CHANGE OR ANTHROPOGENIC ACTIVITIES?

We should take into account that climate change in general is a combination of two factors—natural change and change under human impact. The question from the point of view of Arctic conservation is which factor is crucial and more significant, human climate impact or natural climate change? In my opinion, despite the substantial and sometimes even destructive effects of anthropogenic activity on Arctic regions, the main factor determining the state of the Arctic marine ecosystems with their species or biological communities is natural climate change. My personal opinion is that no anthropogenic warming can result in an increase or decrease of seawater temperature or loss of ice in a local area of the World Ocean that exceeds the effect of natural climate change. History of the stock status and fishery of the Barents Sea capelin could serve as an example of dominance of natural changes over anthropogenic impact. The first collapse of capelin stock in the mid-1980s (cold period) was explained by a combination of various factors, including fishing, poor conditions for reproduction, etc. However, in recent warm years, despite a long-term fishing ban, capelin stocks collapsed three times more and have not recovered. This is caused by the general state of the Barents Sea ecosystem, for example, high mortality from predation of cod and marine mammals, which has intensified in the current warm period.

I would like to address the future of Arctic fishery. Russia currently carries out large-scale fisheries in two marginal Arctic seas, the Barents and White Seas. The basis of Russian fisheries is boreal invertebrates and fish species. Among the Arctic species, only polar cod, nawaga, White Sea herring and a few other species are important for the fishery. Polar cod catches reached 230–330 thousand tons in the 1970s. However, in the past few years, polar cod fisheries are not fully implemented due to a lack of fishermen's interest. Catches of other Arctic species in the Barents and White Seas, and in the future probably in the Kara Sea, are no more than 200–500 tons and these fisheries are largely

Photo 12.4: Common catches in the Barents Sea. *Left,* benthic organisms; *right,* cod and redfish.

carried out by local populations. In addition, local fisheries of whitefish are carried out in coastal brackish waters of bays in Arctic seas, but the catches are also quite low and do not exceed 100–500 tons for the most common species. Due to the low abundance of most Arctic fish (excluding polar cod), a change in commercial fisheries into the Arctic seas is unlikely. Polar cod is also of little interest for commercial fisheries because of its low economic value and the long distance to the fishing grounds. Therefore, at present, fishery cannot have a significant impact on the state of Arctic marine ecosystems. Intensive fishing in the Arctic will be possible only if, due to an increase of water temperature, traditional commercial boreal fish enter the Arctic seas. However, this implies that the habitat in this area is no longer suitable for Arctic species.

So, generally, for me natural climate change is more important for Arctic marine ecosystems compared to human activity.

WHAT CAN WE DO?

Does human society currently have mechanisms that can prevent critical ecosystem changes and preserve the Arctic Ocean? In my opinion, no, it does not have the ca-

Photo 12.5: Common catches in the Arctic waters of the Barents Sea. *Left,* general view; *right,* typical Arctic fishes include *(top)* eelpout (genus *Lycodes*) and *(bottom)* snailfish (*Careproctus* sp).

pacity to reverse current ecosystem change. We can implement economic activities within regulations in order to reduce their impact. For example, we can prevent environmental pollution during hydrocarbon exploitation or from vessels. Or we can prohibit fishing and bottom trawls in protected areas that destroy seabed communities. However, the possible impact of anthropogenic activities occurs at local level. I think this is unlikely to change the Arctic Ocean. Moreover, no more than 5 large cities and ports and about 30 small settlements are located on the entire coast of the Russian Arctic (approx. 22,000 km) and we cannot expect them to make a crucial impact on Arctic marine ecosystems.

Projects such as creating walls on the borders of the Arctic seas preventing the influx of warm water and boreal species into the Arctic, creating and placing cost-effective giant refrigerators or ice generators in the Arctic to prevent temperatures rising or building protective spheres to prevent solar radiation are hardly possible, now or in the foreseeable future. As in the case with the technological developments for keeping polar bears in zoos, restocking technologies for keeping some Arctic invertebrates and fish species in aquaria could possibly be developed in order to conserve certain species. Many of these species are small and attractive due to their body shape and color patterns and can be kept in public aquaria.

Therefore, my opinion is that the future of marine ecosystems in the Arctic is rather optimistic. We can expect that in a while the recent warming period will be replaced by cooling, which could move Arctic marine ecosystems back to their former state, similar to the level of the 2000s–2010s or even the 1950s–1990s.

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CHAPTER 13

FOOD SECURITY AND ADAPTATION IN THE ARCTIC

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ONE ARCTIC—FOOD SECURITY

"Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO 1996). It is apparent that, globally, healthy eating presents significant challenges and that generic food security is not the rule. We are struggling with a food system that is leading to the ill health of many (Kenny et al. 2018). Due to the size, unique geographic and huge variations in climatic characteristics and recent and ongoing societal changes, the mere existence or discussion of a comprehensive global food security or of an Arctic or pan-Arctic food system is challenging and mostly absent from the scientific literature. However, the Arctic regions are experiencing climate, environmental as well as social and economic changes at a rate considerably higher than other regions, and one result of these stressors is increased food insecurity for Arctic populations (Arctic Council 2004). The circumpolar conditions are highly variable but do share some Northern societal transitional characteristics, especially for Arctic Indigenous populations which is the focus of this chapter.

Relatively recently, only a few decades ago, a large proportion of the diet of Arctic people was comprised of country food—locally nutrient-dense harvested wild foods (Arctic Council 2004). Food traditions are important for cultural identity and belonging. Food provides nutrients, is often secured through collective activities and nourishes cultural and ethnic aspects of group dynamics, spirituality and social accountability. These nutritional and cultural benefits of country foods are substantial but also resulted in sustainability of the populations. However, dietary studies now document declining consumption of country foods. The changes in lifestyles include a transition in nutrition, decreasing consumption of country foods and an associated increase in the consumption of carbohydrate-dense processed foods. It is suggested such changes have a more pronounced effect in Indigenous populations. The geographical and cultural variation

Photo 13.1: Cod fisheries take place every winter in Lofoten. These fisheries and the export of fish are at least a 1,000-year-old tradition. The fleet is modern, and a modern food industry is currently developing.

among the Indigenous populations in the Arctic is huge, but at the same time, there are similarities, in particular when assessing challenges for the people still living in remote areas who derive their subsistence from or linked to the natural environment (Sami, Inuit, Dene, etc.).

Other areas, for instance cities or small towns in Northern Norway or northeastern Russia, which are more or less completely *westernized*, have industrial foods fully available in supermarkets and the impacts of the modern food system are evident. In the North, increased prices, higher due to transport and logistics, and lower quality of affordable nutritious food has led to an increased reliance on packaged and processed foods. In addition, as elsewhere, calories are cheaper than nutrients and cheap foods contain sugar, fat and additives, properties that are driving the increased consumption of energy-dense but nutritionally weak foods. Higher consumption of industrial refined food products has led to the elevated, even when compared to the more inhabited southern regions, burden of overweight and obesity. Excessive caloric consumption, unbalanced diets, coexisting micronutrient deficiencies, combined with declining activity levels, imply a growing and earlier onset of lifestyle diseases in particular among adolescents and the younger generation in rural areas (Kenny et al. 2018). Clearly our food system is causing ill health. The impact of the changing food environment is evident worldwide in all societies but are exaggerated in the High North where Indigenous populations are

Photo 13.2: The role of culturally appropriate harvesting in food sovereignty. This critical aspect of food sovereignty includes the right to the traditional harvest, where foods are preserved and prepared according to cultural practices and shared with the family/community.

both genetically and metabolically less able to cope with significant dietary transition. Disentangling contributions of variables is difficult, but the food system is one major driver. Norwegian Sami and Canadian Inuit populations provide some examples of these challenges.

SAMI DIETARY TRANSITION

The majority of the Sami population live in Norway, but we find also Sami in Sweden, Finland and Russia. Similarly to other inhabitants of the Arctic, their subsidence historically came from reindeer herding, freshwater fishing, hunting, gathering and some agriculture. Traditional foods included all parts of reindeer (meat, bones, blood and organs) and fish. Closer to the coast, the proportion of seafood items, in particular lean fish increased and, as with deer, they utilized the complete animal: fish fillet, liver, roe. In addition, the diet included seasonally available foods such as eggs, wild birds, mammals, plants and berries.

Studies on the diet of reindeer herders in Norway, unfortunately based on small sample sizes, have been published only since the 1960s. The dietary patterns revealed a stronger association with the geographical region than by self-perceived classification as Sami, Kven (a Balto-Finnish ethnic minority in Norway, they descended from Finnish

Photo 13.3: Salmon and Arctic char are an important aspect of the Arctic economy. A salmon farming industry has developed over the last 40 years *(left)*. The salmon are held in cages, as shown here, and the technology includes plastic and steel cages, nets, camera systems, environmental sensors, underwater lights, and production and process control software. Arctic char *(right)* are part of a commercial fishery in the Canadian Arctic that relies on Inuit harvesting seasonally with nets.

peasants and anglers who emigrated from the northern parts of Finland and Sweden to Northern Norway) or Norwegian. As expected, fish was associated with the coast and reindeer was common inland.

A more recent epidemiological SAMINOR study from UiT The Arctic University of Norway,[1] estimated current food intake in the Sami compared with the Norwegians in municipalities within northern Norway. Sami diets contain more reindeer meat, moose meat, animal blood products, freshwater fish and less lean fish and vegetables. Compared with the inland region, fish items (fillet, roe and liver intake) were higher along the coast and lean fish intake doubled. Compared with non-Sami or Norwegians, those with Sami background reported a significantly different intake of several foods within the same geographical region. Thus, the diets do vary between the different groups of people in the North, the availability of shop-bought food items and geographical distribution significantly contributes to this variation.

When SAMINOR data were classified and associated with education and socioeconomic as well as physical activity, fish consumption was associated with older age, high education level and small household size. The differences were significant but small. Adherence to the processed meat/westernized consumption pattern was lower among inland Sami than Norwegians and those with mixed background and associated with low physical activity, smoking and age. Low education and income, as well as large household size were associat-

[1] See https://en.uit.no/forskning/forskningsgrupper/gruppe?p_document_id=591555

ed with a sweets and bakery goods pattern. The healthy fruit/vegetables pattern was more common in women with a high education level and income. When comparing SAMINOR 1 (2003–4) and 2 (2012–14) it was detected that youth or age at baseline is associated with increasing weight and waist circumference. As elsewhere, this applies to all, irrespective of both sex and Sami/non-Sami or Norwegian ethnicity (Petrenya et al. 2018, 2019).

Some Arctic inhabitants rely on wild-caught as well as cultivated marine and terrestrial resources for their subsistence and livelihoods. Additionally, in some areas, fisheries and aquaculture from Arctic food resources are contributors to global food security and improved nutrition. This represents significant potential for circumpolar communities in line with the United Nations Agenda 2030,[2] the Sustainable Development Goals (SDGs) and the proposed Decade of Action on Nutrition 2016-2025.[3] Despite the opportunities, access to Arctic foods is constrained by knowledge and infrastructure resources that restrict development of sustainable harvest and aquaculture initiatives (Arctic Council 2004).

INUIT DIETARY TRANSITION

Food security is a critical issue for Inuit populations in Canada as illustrated by the International Polar Year Inuit Health Survey. It showed that Nunavut Inuit experience food insecurity at a rate higher than any other Indigenous population in the world and that children are at the greatest risk (www.inuithealthsurvey.ca). Hence, a lot of recent research attempts to describe the contexts for the issue and to point to potential solutions for resolving it. The Government of Nunavut and the Nunavut Tunngavik, the legal representative of Inuit in Nunavut, have joined forces to create a poverty reduction strategy with a key focus on food insecurity. Stemming from all this activity is some consensus around the need to focus on the promotion and production of healthy local foods, and the development of a Northern food industry.

For Arctic Indigenous populations food security has always been the driver in group interaction, socialization and cultural activity. Cultural norms that emphasize sharing things, but especially food, led to intricate relational networks that helped define how to share and secure the greatest well-being of the group. These practices have diminished over time but have not disappeared. Food ensures sustainability and therefore food acquisition and sharing are critical to survival in the harsh Arctic conditions, even today. For Inuit, the discussions around food security are often confusing. Food security looks at issues of hunger and access to food through existing food regimes. For Inuit, the issues are more in line with views on food sovereignty. This speaks to the importance of access to foods as part of cultural and social identity. Being able to control and locally

[2] See www.UN.org>sustainabledevelopment>decade-of-action.

[3] See https://www.un.org/nutrition/

Photo 13.4: Stockfish production, seasonal cod fisheries, Lofoten.

manage one's food production and consumption is important in environments where food access is never a given. Ensuring access to the training, information, and skills to achieve food security also becomes critically imperative (Kenny et al. 2018). There is recognition that for Arctic Indigenous populations the historical connections between culture and food hold the greatest potential for lasting positive impacts.

From this perspective, it becomes increasingly important to consider the community contexts and existing initiatives in terms of building a food sovereignty approach for the Arctic. "Long-term alleviation of food insecurity requires drawing on the assets, capacities, and abilities of Northern communities, as well as addressing numerous factors that contribute to the inequities underlying food insecurity. This affirms the importance of food sovereignty as a means by which to achieve food security" (Council of Canadian Academies 2014).

It may be appropriate going forward to rethink an approach, which is more grounded in a food sovereignty paradigm, with a broader holistic approach that supports localized and

Photo 13.5: The crustacean fisheries in the Barents Sea target deep-sea prawn and red king crab. The king crab picture *(right)* was taken outside Bugøynes (on the coast) and the shrimp picture *(left)* from Svalbard (high seas). Norway dominates the shrimp fishery. Red king crab is fished by Russia in Russian waters, and by Norway in the coastal waters of its northernmost county.

Photo 13.6: New cuisine from traditional Sami food. In recent decades, new influences are making themselves felt in traditional Sami cooking, and new products and dishes are emerging. The old food culture is evolving and adapting.

culturally intrinsic food solutions and to redefine access and local food and agriculture systems. Discussions around food security in the Canadian Arctic have focused largely on inequity of access. Market foods are expensive, often unavailable, of poor quality and tend to have limited health benefits for Inuit (Kenny et al. 2018). Increasingly, there are initiatives aimed at returning to food sourced through local harvesting and production. Sourcing food closer to home is a global movement that has vast potential, but also significant challenges for dense populations. For Inuit in the past, it was always the only option. Today it is seen as the preferred option to address issues of poverty, food security and food sovereignty. Local harvesting and production can provide employment and secure fresh and cost-effective food. In terms of strategic investment, serious planning for economic development of local food production is being called for across Inuit Nunangat.

STRATEGIC INVESTMENT IN HEALTHY EATING FOR INDIGENOUS POPULATIONS

Healthy food needs to be considered in light of climate change impacts, which are creating new and different opportunities for food production and sustainable harvests. For example, utilizing more sea mammal meat, duck and goose harvesting, and harvesting new or underutilized marine species holds potential. New technologies provide options such as dehydrating wild eggs, aquaculture (fish farming) associated with hydroponic greenhouses, and exploring the potential for increased seasonal agriculture. The Arctic is experiencing warming spring/summer temperatures, changes in weather patterns and warmer ocean conditions. The results are both an increase in some species populations and the introduction of new species. These opportunities come at a time when the skill and ability to harvest sustainably is declining in many areas. However, they also come at a time when technology can significantly improve the production and preservation of local food sources. It will be important, going forward, to look at the potential for sustainable harvesting and food production enterprises that can build capacity, build on existing community strengths and ensure long-term employment and investment potential (Arctic Council 2004).

A key consideration is the safety of food products, given impacts of climate change and the increase of environmental contaminants. The Arctic Monitoring and Assessment Programme (AMAP 2010) has predicted higher contaminant levels in a variety of Arctic species. Attention to this comprehensive assessment project will be critical to establishing both species sustainability and food safety. There will be requirements for regulations around testing/handling of wild products, monitoring and maintaining of standards of production. These are definitely challenges for Northern production, but especially for local production centers in isolated areas. Infrastructure is another very demanding requirement since almost none currently exists. Consideration of how to safely secure, preserve and transport products must be explored and addressed (Arctic Council 2004). It is expected that branding and marketability of Northern products will have positive results and eventually sufficient return on investment.

A key consideration in terms of strategic investment is actually the extremely high costs of health care in the Arctic. Almost all serious health care issues are attended in southern medical centers which entails travel, accommodations, lost wages and delays in treatments. Most health care issues facing Inuit can be traced to unhealthy diet and lifestyles. Chronic disease such as cardio-vascular disease and Type 2 Diabetes are increasing at horrific rates, while cancers such as colon-rectal cancers also take their toll on Arctic Indigenous populations. These are diseases that were largely unknown historically.

A significant challenge to the food sovereignty mosaic is the challenges presented by poor nutrition and diets in transition. For Inuit, historically all food available was safe and healthy and all food was consumed (except the liver of the polar bear). Inuit, over centuries, had developed an efficient genetic and metabolic response to cold conditions through the consumption of a high protein, fatty acid diet. This diet is particularly responsible for the more positive health conditions they experienced before dietary transition. The fact that few carbohydrates and very low sugars were ever consumed left them at very high risk for unfavourable health impacts when a very sudden and drastic dietary transition took place in their lives. The Canadian government policy of forced


Photo 13.7: Supporting sustainable harvesting supports positive health indicators. Locally harvested foods are more nutritionally dense and are better suited to an Indigenous metabolism. Access to these foods helps to address health challenges such as type 2 diabetes and heart disease.

relocation resulted, for many, in an overnight transition from this protein-based, fatty diet to a largely processed carbohydrate-based/energy-dense diet. The health impacts have been devastating for Inuit (Kenny et al. 2018). Food sovereignty requires the ability to return to a healthier diet with access to those foods that are locally harvestable. A return to locally harvested wild foods is thus a strategic investment in long-term health improvements and a reduction of healthcare-related costs.

RETURN TO HEALTHY EATING

Returning to a nutritionally dense, locally available and sustainable food system seems a very viable option. However, its success will require the challenging of several food myths and practices that have taken root in Northern communities. In Arctic Indigenous communities, the myth that in order to eat well, you need to access mainly market foods and eat according to recommended dietary guidelines has contributed to ill health through an overreliance on store-bought food. There is also an underlying assumption that poor people eat country foods while wealthier people buy food at the stores.

There has been much misinformation and alarm about contaminant levels in Northern foods. In fact, the contamination levels for the majority of foods and most consumers, are outweighed by the nutritional advantage of the food. This message has to be balanced, to do more good than harm, and asserted in communities where there has been misinformation or misunderstanding in the past. Messaging needs to ensure that dietary changes are favourable and protect the part of the population at greatest probable risk, notably women of childbearing age and children. It should also address the need for lifestyle change and training around healthy eating. Challenging these myths will require concerted public awareness campaigns and some directed realignment of food preferences, especially for youth, who generally have had less exposure to, and less consumption of country foods. In some communities where concerted work on food security initiatives has taken place efforts in this direction have been successful.

Photo 13.8: Arctic greenhouses provide answers to the high cost of transporting foods. The availability of locally grown produce supports changes in dietary tastes and intake, and provides cost-effective alternatives for consumers.

These aspects of food sovereignty need to be addressed in a comprehensive approach that embraces the potential for the development of sustainable local food production efforts that address economic, socio-cultural and health issues simultaneously. Infrastructure investment and economic development grounded in local control and cultural practices and expertise are required. The approach will also need to be supported in comprehensive policy reforms and legislation.

CONCLUDING REMARKS

In seems apparent that local food production holds a healthy potential for pan-Arctic populations and possibly for mainstream populations as well. This potential is worth serious exploration and the possibility of sharing learned experiences and perspectives could facilitate health and food security improvements. European Northerners, particularly Sami reindeer herders, Norwegian and Greenlandic fishers, are ahead of North Americans in the commercialization and successful marketing of country food products. There is much that can be shared in terms of regulation, safety standards and sustainable production processes. The development of both formal and informal markets, employment options and supporting policies, legislation and investments are critical to facilitating broad access to healthy local foods.

Indigenous populations have historically harvested widely and consumed a very varied diet. Many of these foods are no longer consumed regularly. However, there is potential to assess the sustainable harvest of some of these foods and to reintroduce them. Much of the food insecurity experienced in northern regions is associated with unemployment and poverty. A revitalization of harvesting activities and the establishment of local food production facilities present many opportunities to address Arctic food security in a number of innovative ways (Arctic Council 2004), as well as providing new food sources for other populations.

The worldview of the Arctic Indigenous populations, both individual and collective, is considered holistic with regard to nature and well-being. It touches on all aspects of existence. Food insecurity and poor nutrition may be shared concerns for the health of Northerners, but well-being is also significant (Arctic Council 2004). In considering a sustainable future for the Arctic, it will also be critical to consider dimensions of human development as part of a food sovereignty approach; ability to control own destiny, maintaining cultural identity and living close to nature. We see the potential for Northern sustainable harvesting as important to addressing these important dimensions. Through restoring long held cultural practices of sustainability and by supplying the world with *local*, healthy food we may perhaps create a broader foundation for health and well-being in the Arctic.

Various risk factors including impact of climate change as well as infrastructure and logistical disruptions represent prevailing risks throughout the Arctic. Food security incorporates a measure of resilience to future disruption or unavailability of critical food supply. The connection between health, social performance and healthy food is indisputable, and if we want to make our communities healthier it is crucial that we connect people with the resources they need to achieve this health. Food security is thus a priority as healthy eating is fundamental for good health in the broadest meaning of the term. Future approaches will include knowledge to ease the transformation of economic, so-

Photo 13.9: Coastal herring fishing in northern Norway.

cial, and other policies and regulations to ensure food security at pan-Arctic or circumpolar scales. Climate change has ecosystem impacts that are reflected in human food security, safety and health. It is important to trace these impacts to comprehend how these changes affect food security, nutrition and health. In all our efforts, investigations and planning to achieve sustainable healthy futures, it is important to base our activities on the local contexts of the Arctic and to work alongside the strengths and resources that already exist. In this way, the Arctic may provide food system models of local food production for other regions.

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CHAPTER 14

GEOSCIENCES IN THE CENTRAL ARCTIC OCEAN

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In 2009, the United Nations' Continental Shelf Commission decided to support the Norwegian claim for an extended continental shelf north of Svalbard, into the Nansen Basin. The participants of a gathering of geoscientists at the University Centre in Svalbard, UNIS, were at that time discussing the extension and agreed that the knowledge base was limited. Exploring the Central Arctic Ocean had not been given priority in Norway in recent years. Five years later, the scientists formed a consortium to pursue the challenge, called GoNorth (Geosciences in the Northern Arctic).

The Norwegian Government has defined the Arctic as its most important strategic foreign policy area, requiring presence and knowledge. The government's updated Ocean Strategy, Blue Opportunities, addressing knowledge building and sustainable development, adds a new dimension to the policy.

We acknowledge that international scientists have been more active in the Central Arctic Ocean than Norwegian scientists in recent years. Therefore, international collaboration has been identified as a major success criterion for exploring the Central Arctic Basin, both for scientific, logistical and financial reasons. The logistical challenges will be substantial and two ships working in parallel will be essential to achieve results. Norway has a brand new ice-going research vessel, RV *Kronprins Haakon*, with superb instrumentation. We can make full use of its capabilities through working with other ice breakers like the German RV *Polarstern* and the Swedish RV *Oden*.

The area north of Svalbard contains several geological enigmas. Major, yet unanswered, scientific questions are:

1. Why is the passive, extensional continental margin north of Svalbard unusually narrow, with main characteristics comparable with laterally sheared margins?

Photo 14.1: Iceberg transporting large amounts of rocks off the northeast Greenland shore.

2. Why is the hydrothermal activity along the ultra-slow spreading continental rift, the Gakkel Ridge, located halfway towards the North Pole from Svalbard, similar to much faster spreading ridges?
3. What was the climatic, glacial and paleo-oceanographic development of the Arctic during the past ~65 million years, and where do we go from here?

Even though new and important geological/geophysical data have been acquired from the Central Arctic Ocean in recent years (e.g., by the Norwegian Petroleum Directorate, the Alfred Wegener Institute (AWI), the German Federal Institute for Geosciences and Natural Resources (BGR) and the Russian VNIIO/GINRAS), the understanding of its geological history and sea-floor conditions remains limited. This is partly because the area is logistically demanding, as the sea-ice cover poses challenges on data acquisition.

The southern part of the continental shelf in the European sector of the Arctic Ocean is generally shallower than 400 meters and mostly ice-free during summer. The Nansen Basin, which forms part of the Eurasia Basin, is located between the northern margin of the Barents shelf (Svalbard and the Yermak Plateau) and the Gakkel Ridge. On average, the basin is 500 km wide, 3,700 m deep and largely covered by pack ice. Knowledge about the sedimentary sequences in the Nansen Basin remains sparse.

Svalbard is a geological laboratory, containing deposits from all geological periods, that can be used to obtain an understanding of the structural features in the marine realm further north. Geological and geophysical data from Svalbard will help to improve the understanding of this structural framework and basin development in the Central Arctic Ocean. This onshore-offshore linkage will be exploited as part of our research.

On the basis of existing seismic and gravimetric data, as well as heat flow measurements, the southern and northwestern segments of the Yermak Plateau are inferred to comprise thinned continental crust. This interpretation is supported by petrographic, geochemical and geochronological analyses of samples recovered from the sea floor. The greater mass of the Yermak Plateau may, thus, constitute a direct structural continuation of the northern part of Svalbard. Furthermore, bathymetric features and geological structural trends on the plateau are similar to those we encounter in northern Svalbard.

The supposed oceanic segment of the Yermak Plateau is covered by an up to 2000 m thick sequence of sediments. The oldest sediments may be approximately 35 million years old. They may be older in the deepest sub-basins. The Ocean Drilling Program sites 910 and 911 drilled through younger sediments in the northwestern part of the

Photo 14.2: Mix of *clean* and *dirty* sea ice in the Central Arctic Ocean. Dirty sea ice contains sediments from the shallow-water sea floor and shorelines of the Arctic Ocean. Entrainment of sediment into sea ice is particularly abundant offshore in Northern Siberia. A large part of the dirty sea ice is subsequently transported across the Central Arctic Ocean towards the Fram Strait in the Transpolar Drift.

Yermak Plateau. These cores provide valuable information about the environmental development of the southern part of the Central Arctic Ocean during the past 5 million years.

Svalbard's northern margin, east of the Yermak Plateau, is interpreted to represent a passive continental margin. However, continental stretching is localized, and the area thus exhibits features that are more similar to a sheared margin. Preliminary geodynamic modelling indicates that the margin may have been subject to a short period of shear deformation before extension became the dominant mechanism during margin formation. The margin appears, furthermore, to be very little influenced by volcanism that often masks the tectonic processes in other locations. Thus, Svalbard's northern margin is a unique laboratory for studying the links between shear and extensional movements during continental fragmentation.

THE GAKKEL RIDGE—A MAJOR CHALLENGE

The Gakkel Ridge is a continuation of the Mid-Atlantic Ridge extending into the Arctic Ocean. It extends for 1800 km through the Eurasia Basin and continues until it meets the broad continental shelf north of the Laptev Sea, offshore of the Lena River estuary.

The spreading rate along the Gakkel Ridge decreases from 0.7 cm/year north of Svalbard to 0.3 cm/year close to the Siberian continental shelf. This makes the Gakkel Ridge the slowest spreading ridge on Earth, which has fueled speculation that it is formed in a different manner than other oceanic spreading ridges. Given that the Gakkel and Mid-Atlantic Ridges belong to the same system, the Eurasia and North Atlantic Basins must have been formed by the same process. It is assumed that the Arctic Ocean began to open at the same time as in the North Atlantic.

During this early opening phase of the Arctic Ocean, plate movements were such that Svalbard and Greenland moved laterally in relation to each other, while marine basins opened in the north and south. Subsequently, plate movement changed to a direction similar to today. The Fram Strait between Svalbard and Greenland became deep enough to allow deep-water exchange between the Eurasia Basin and the North Atlantic at the earliest approximately 17 million years ago. This possibility for deep water masses to flow from north to south and vice versa through the Fram Strait significantly changed the prevailing Atlantic climate regime and oceanic circulation patterns.

In situations where spreading rates are low, such as along the Gakkel Ridge, the Earth's mantle is relatively cold and volcanic activity is limited. This results in an incomplete development of the oceanic crust to the extent that the mantle gradually extends all the way up to the sea floor.

Photo 14.3: Dense sea-ice cover with scattered ice ponds, open leads and ice ridges in the Central Arctic Ocean.

Hydrothermal systems are encountered along the spreading ridge at locations where sea water migrates into the basalts of the oceanic crust and at some locations into the mantle. Here the water is heated and then forced upwards, back to the seafloor and into the water column. Some of this water returns through so-called *hydrothermal vents* on the sea floor, from which fluids are discharged at temperatures of up to 400 degrees Celsius. The volume of this hydrothermal cycle on a global scale is approximately one-seventh of the volume of the hydrological cycle on land. The fluids discharged through the vents lead often to the accumulation of volcanic massive sulfide deposits on the seafloor that are characterized by high concentrations in metals such as copper and zinc. Such metals are of tremendous value for modern technologies needed to reduce greenhouse gas emissions. However, the knowledge base of such systems remains limited.

THE GREENHOUSE-ICEHOUSE EVOLUTION OF THE ARCTIC

The Arctic Ocean has been exposed to repeated dramatic climatic and environmental changes during the past 65 million years. This includes the long-term transition from a greenhouse climate with surface water temperatures of up to 25°C approximately 65-35 million years ago, to full icehouse conditions with perennial sea-ice cover. Many of these environmental changes and their causes remain poorly understood, and reconstructions are fragmentary, thus, requiring additional investigation and integration of terrestrial and marine records. Knowledge about the past is essential for predictions of the future evolution of the environmental conditions in the Arctic Ocean.

Recent studies provide evidence for periods of sea ice as early as ~47 million years ago, implying that freshwater supply played a crucial role in the hydrological cycle in the Arctic Ocean. Ice-rafted debris in sediments in the Arctic-Atlantic gateway region, indicates the presence of circum-Arctic ice sheets. The following periods are characterized by a marked global cooling. However, only fragmentary knowledge is available for the transition and the history of the deep-water connection between the Arctic and Atlantic Oceans.

More extensive glaciations in the Atlantic-Arctic gateway region did not prevail until 20 million years ago, with stepwise intensification since the onset of glaciations around 2.6 million years. Reconstructions suggest that the Arctic Ocean went from an isolated, oxygen-poor *lake stage*, to a transitional *estuarine sea* phase with variable ventilation, and finally to the fully ventilated *global ocean* phase. This inferred formation of the Atlantic-Arctic gateway must have had a substantial effect on high-latitude circulation and water-mass exchange. However, the exact timing is still uncertain due to coring gaps. To date, we have clear evidence for a fully established deep-water exchange between Arctic and Atlantic since about 6 million years ago.

Major cooling took place at around 2.6 million years ago, when Earth's orbitally driven factors led to repeated fluctuations between glacial and interglacial cycles. However, the extents of ice sheets remain poorly known. The first reconstructions ranged from 1 km thick ice caps to perennial sea ice with icebergs. Recent studies found evidence of grounded ice shelves on bathymetric highs in the Central Arctic Ocean, suggesting the existence of a coherent, up to 1 km thick, ice shelf in the Central Arctic Ocean around 140 thousand years ago. The sediment transport during glaciations occurred predominantly by ice streams that eroded deep cross-shelf troughs and deposited sediments at the outer shelf and upper slope. The chronologies of the glaciations remain incomplete.

Understanding the advances and retreats of the Svalbard-Barents-Kara Sea Ice Sheet during the last glaciation, is highly relevant beyond its regional scale. It contributes to the understanding of global sea-level and climate changes, and it can be used as an analogue to better understand current processes occurring within and at the margins of the Greenland and Antarctic Ice Sheets, respectively.

The basal conditions beneath the ice sheet varied largely between areas of cold-based and relatively inactive ice, and warm-based, fast-flowing ice draining multiple ice domes through fjords and cross-shelf troughs. Fast ice flow resulted presumably in relatively

Photo 14.4: Kongsfjorden in Svalbard. Whereas the Svalbard mountains archive and reflect a myriad of geological processes and environmental changes dating back over more than a billion years, glaciers and fjords can be investigated to better understand the impact of more recent climatic changes on Svalbard (example from Kongsfjorden).

thin ice masses on Svalbard and the local appearance of nunataqs, but also the existence of thin, cold-based ice fields between the ice streams.

The deglaciation of the northwestern Barents Sea and Svalbard mainly took place after 20 thousand years ago. It was interrupted by multiple halts and/or re-advances and terminated in most of the inner fjords around 11 thousand years ago. Despite numerous works addressing the glacial history of the Svalbard-Barents-Kara-Sea Ice Sheet, many of the results are conceptual and fragmentary so that more firm data from marine and terrestrial records are needed for a more comprehensive understanding of past ice-sheet and glacier dynamics. This includes also the sea-level history on the northern Svalbard margin which is, thus far, based on old and incomplete data sets.

OTHER SCIENTIFIC PRIORITIES

The scope of our ambitions has broadened to include new technology, as well as research related to the water column and the sea surface. The main tasks in developing and testing new technology are related to maritime operations in Arctic areas, underwater operations, communication and navigation technologies, and environmental and geophysical surveying methods. Available infrastructure includes ships, remotely operated vehicles and sensors.

Physical and biological processes in the water column under the Arctic sea ice are poorly understood. Even though the ongoing climate change in the Arctic is well documented, many open questions about the role of the Central Arctic Ocean in the global climate system remain. It would be helpful to deploy a pilot for a year-round multi-disciplinary observing system to collect oceanographic data including ocean temperature, acidification, sea level, sea-ice thickness, vocalizing marine life, acoustic impact of human activities, and geophysical hazardous events (e.g., earthquakes, landslides, tsunamis). Another major oceanographic objective will be to investigate the variability and interactions between the inflow of warm water north of Svalbard, the Transpolar Drift and the Beaufort Gyre.

The complex interactions between the biosphere, hydrosphere and cryosphere are central, yet poorly understood features of the Central Arctic Ocean. A perturbation in one or more may propagate and amplify through the interactions, resulting in disproportionally large changes and/or regime shifts. Disproportionally fast warming of the Arctic and loss of sea ice are well-known examples of such amplifications that will eventually result in a seasonally open, highly illuminated, and freshened Arctic Ocean. Knowledge is needed to better understand how physical, biological and biochemical drivers regulated by the presence of sea ice, influence the ecological processes in the water column below.

A geopolitical dimension, looking into how scientific knowledge may translate into political power, from historical and contemporary perspectives, and how the science-policy interface works in global governance, is also of interest in this context.

EPILOGUE

On August 30, 2014, Professor Yngve Kristoffersen from the University of Bergen and Audun Tholfsen from the Nansen Environmental and Remote Sensing Center in Bergen, were deployed on the sea ice by the German icebreaker RV *Polarstern*, close to the North Pole. With the hovercraft *Sabvabaa* as expedition base (*Fram 2* expedition), the scientists drifted through the Central Arctic Ocean and crossed the Lomonosov Ridge repeatedly on their path towards the Fram Strait between Greenland and Svalbard, where they were picked up in the following summer. During the drift, unique oceanographic, atmospheric and geoscientific measurements and observations were made. This was the first Norwegian ice-drift expedition since Fridtjof Nansen and RV *Fram* drifted across the Central Arctic Ocean 120 years earlier. It attracted limited attention among the general public, but scientists around the world admired the effort.

Photo 14.5: Sediment core retrieved from the Central Arctic Ocean during Expedition PS87 by RV *Polarstern*. The varying sediment colors and compositions are archives of past climate change.

On August 21, 2019, the Norwegian coast guard ice-going vessel KV *Svalbard* reached the North Pole, the first Norwegian ship ever to do so. The cruise was part of the research program CAATEX (Coordinated Arctic Acoustic Thermometry Experiment) aiming to collect environmental data from the atmosphere, sea ice and the ocean. The team deployed oceanographic rigs across the Eurasia basin. CAATEX is coordinated by the Environmental and Remote Sensing Center in Bergen, with national and international partners, including the Norwegian Polar Institute, Scripps Institution of Oceanography, Woods Hole Oceanographic Institution, University of Texas at Austin, University of Bergen, NORCE, NTNU, Norwegian Meteorological Institute, Institute of Oceanology at the Polish Academy of Sciences, and National Institute of Ocean Technology in India.

Fridtjof Nansen's ice drift expedition with RV *Fram* in 1893-96 was believed to be the beginning of an era for Norwegian explorers in the Central Arctic Ocean. This belief did not become a reality. Roald Amundsen explored the North West Passage, while Nansen's skipper Harald Sverdrup made ground-breaking discoveries and performed extensive mapping along the western coast of Greenland, up towards Ellesmere Island. It was Russia that picked up on Nansen's ice drift concept and initiated more than 30 expeditions between 1937 and 1990, using ice floes as research and logistics platforms.

In the 1980s, ice breakers dedicated to research started appearing in the Central Arctic Ocean, among them the German RV *Polarstern*. In recent years, there have been international ice-breaking expeditions every summer led by a variety of countries, including Russia, Sweden, Finland, Canada, China, South Korea and Germany.

The *Fram 2* and KV *Svalbard* expeditions have been great inspirations for other Norwegian scientists wanting to re-establish a Norwegian scientific presence in the Central Arctic Ocean and contributing to international knowledge building in the Central Arctic Ocean. It is about time.

CHAPTER 15

TESTINATION NORTH

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Norway plays an important international role as one of the main actors in the blue economy. More than ever a holistic and sustainable approach is needed to address *global challenges*, *value creatio*n and *knowledge-based management* of the Arctic regions and oceans, and Norway attempts to contribute to this goal.

We are heading into the United Nations Decade (2021–2030) of Ocean Science for Sustainable Development—The Science We Need for the Ocean We Want.

The symptoms or effects of changes in the environment and climate caused by human activities may be most pronounced and visible in the High North and Arctic regions giving us clear hints where we are heading for better or worse (Wassmann 2011). The High North is also well suited to developing and qualifying technology to withstand extreme environments taking us to a better future. Hence, we may consider the High North as a *test destination* area for measuring the effect of human activities and technological progress. Motivated by similar considerations coined by the Norwegian agency Innovation Norway in a seminar in Svalbard February 2019, I will therefore entitle this essay: "Testination North."

A HOLISTIC VIEW ON SUSTAINABILITY CARING FOR THE PLANET OCEAN

A holistic and sustainable perspective on the blue economy (figure. 15.1) that embraces all stakeholders, including policymakers, is needed in order to achieve both the impact and implementation at the speed we require. The changes that take place in Arctic regions and seas are increasing in speed and extent and are strongly interconnected to activity on land and coastal areas around the globe. The oceans are connecting us, and we are in a hurry to understand and take proper actions.

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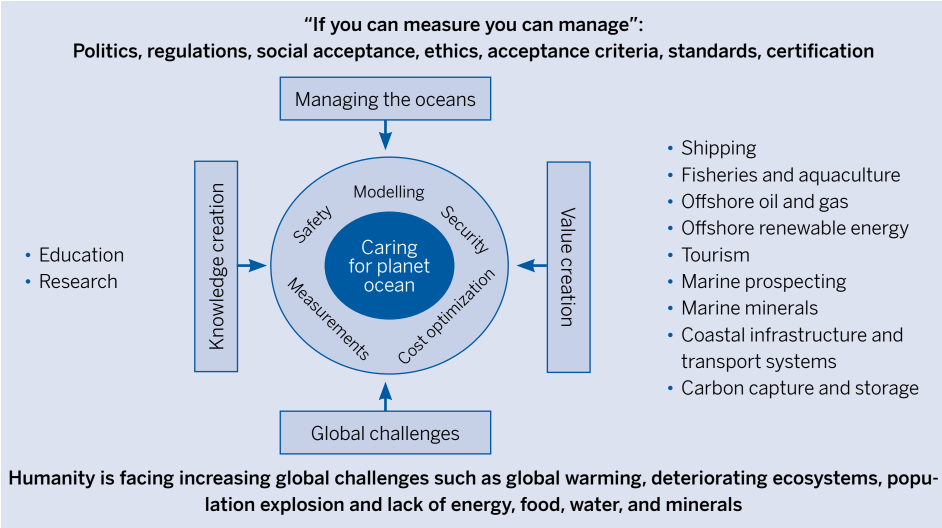


Figure 15.1: Sustainable Development Goals of the United Nations. These goals define the rules of the game by setting a new global agenda. From a holistic sustainability perspective, knowledge creation must address global challenges, governance, and value creation.

Being a part of the knowledge sector, we have a responsibility to develop competence, knowledge and innovations relevant to:

- *Global challenges* related to climate, energy, minerals, food, clean oceans, biodiversity and logistics
- *Value creation* (products, services, etc.) in terms of fisheries, aquaculture, maritime transport, oil and gas exploitation, offshore renewable energy, marine minerals, tourism, coastal and urbanization infrastructure
- *Governance and knowledge-based management* of the oceans, coastal areas and the Arctic

When it comes to preserving and developing human health and well-being in the short and long term for the generations to come, we face a number of dilemmas. Increasing occurrence of extreme weather, accelerated melting of ice on land and sea, rising sea levels, pollution, and global diseases should motivate us to develop towards sounder and more sustainable human activities. The cost of overlooking this fact will simply be too high both in economic and humanitarian terms. Indeed, it is my believe that knowledge and competence can contribute to technological innovations and policy in two manners. If we are to generate sufficiently fast changes in the right direction some technological innovations may be implemented as a transformative process while others may be more disruptive. Successful implementation relies on political leadership that enforces incentives and regulations. Fortunately, long-term responsible industry actors and investors who look beyond the next quarterly financial report have similar interests. There does not need to be a contradiction between value creation and sound knowledge-based governance. For instance, in the fisheries and aquaculture industry it is quite obvious that a healthy ocean is not only good for, but a precondition of business.

Being proactive we may regard the 17 United Nations (UN) Sustainable Development Goals (SDG) as the largest and most systematic market study of the world, providing possibilities for economic growth and a better future. Knowledge and competence will be instrumental for the development of technology and services that contribute to improved solutions.

Decades of systematic research using ships, landers and buoys, and lately advanced marine robotics and sensors have told us how extensive and vulnerable the ecosystems are in the High North and Arctic Ocean, including *marginal ice zone* waters (a mixture of open and ice-covered water). Even during the winter and polar night season the marine ecosystems are fully functional and active. Threats to these ecosystems span from discharge of toxic substances, inflow of warm water and the intrusion of invasive species from the South. During the polar night we have also studied how sensitive the behavior of zooplankton and fish are to artificial light pollution (e.g., ships, settlements). The light climate influences the hunting and escape strategies for a large number of species such that they easily become disturbed by artificial light several kilometers away from the source as well as tens of meters deep. The same behavior using large ships emitting light may also be a source of error in quantification of marine resources for research and management purposes during the night and winter season (polar night).

We may claim that the advection pump of warm Atlantic water into the Arctic Ocean and the corresponding outflow of cold Arctic water, both taking place in the Fram Strait between Greenland and Svalbard, are of crucial importance for life in the northeastern North Atlantic and the Arctic Ocean. Any changes in these water fluxes do not only directly affect the local climate but have ramifications all over the Northern Hemisphere. In simple terms we can regard the Fram Strait as an oceanographic and biological *war zone* between the South and North. Today's climate change moves this war zone further North with devastating effects on the Arctic sea life including sea birds. As in the ancient times of the ice age the pressure by human exploitation of resources in the Arctic regions literally follows the ice edge. This also applies today for whaling, fisheries, shipping, tourism, mining, oil and gas.

THE BLUE ECONOMY

The Norwegian economy is dominated by the blue economy (figure 15.2). Common factors in all blue economy activities are that they take place in the oceans and are both local and global in their presence and trade. Concerning a more accessible new Arctic Ocean we may foresee a global race to secure access to potential valuable fisheries, hy-

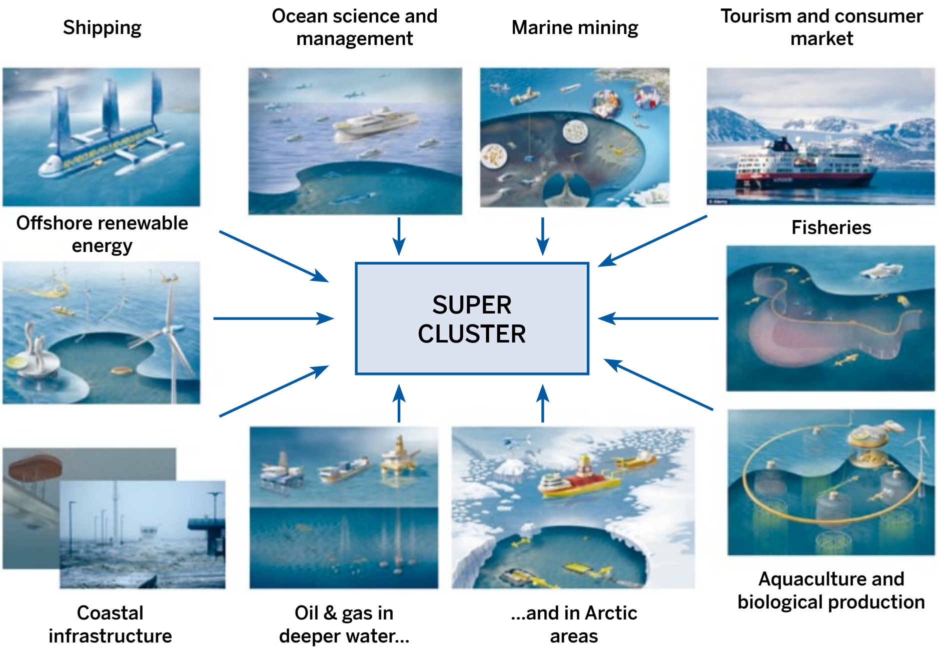


Figure 15.2: Norway as an example of High North and Arctic Ocean space industries. The blue economy is contributing about 90% of the nation's export revenue, a large portion of which takes place in the High North.

drocarbons and mineral resources. In addition, less multi-year sea ice will open up new Arctic shipping routes. Hence, the level of human activities and possible environmental impact are expected to increase in a vulnerable environment where our knowledge is still rather limited.

Offshore oil and gas, maritime industry and fishery and aquaculture are the three largest sectors of the Norwegian blue economy. They are all of great importance for Norwegian well-being, providing an important contribution to the world in the supply of energy, transportation and food. Emerging business areas are offshore renewables (primarily offshore wind), tourism and marine mining. Benefitting from ocean science and bioprospecting (the process of discovery and commercialization of new products based on biological resources) we may also see huge potentials in new marine species, bacteria, molecules, etc., for the production of new pharmaceutic substances.

National oil and gas activities mostly takes place in three areas—the North, Norwegian and the Barents Seas. Debate over defining the border line for the sea-ice edge in the Norwegian Arctic regions restricting how far north oil and gas activities on the Norwegian continental shelf can take place has been intense. Oil and gas activities in the High North are not only of concern in Norway. There are also large terrestrial and offshore activities in Russia, Canada and the United States. Exploitation of hydrocarbons is unsustainable per se. However, according to the energy forecasts by the International Energy Agency (IEA) oil and gas will still be a vital part of the world energy mix during the next few decades. Carbon capture and storage (CCS) in ground reservoirs and other capturing methods in the ocean (e.g., kelp and micro algae production) may be creative methods to reduce the problem. Work to replace polluting energy sources such as coals and heavy oil with cleaner sources using natural gas and renewables has intensified. Even nuclear power production is considered sustainable by many. Nuclear power may even be considered *green*. We may ask ourselves what criteria we apply to the various solutions to address humanity's needs.

Maritime transport is probably the most environmentally friendly method to transport large amounts of goods and humans to secure primary logistics needs. However, shipping may be one of the most severe single sources for greenhouse gases, black carbon and unintentionally causing the spread of invasive species with ballast waters and hull fouling. The UN International Maritime Organization (IMO) has therefore enforced a plan to reduce emissions in international shipping in total by 50% in 2050 compared to the 2008 level. A reduction on up to 50% may not look ambitious. However, it will create changes in the organization of logistic chains and incentivize new ship concepts with hybrid power plants using greener fuel mixtures, batteries, hydrogen, etc. Reducing ship speed and selecting unmanned autonomous ships will represent possible solutions. A driver for rapid transition in global shipping, may be to enforce even stricter requirements for reduced emission in all maritime activity in the Arctic region. This may be regulated using e.g., taxes on emissions.

Aquaculture is currently struggling with ectoparasites and harmful algae blooms. In addition, the environmental impact of aquaculture is of concern in many fjords. Offshore aquaculture in more exposed areas has become the next step for growth in this business. It is likely that the activity level will move northwards and to areas with better access to natural supply of food for farmed fish, such as the dominant zooplankton species *Calanus finmarchicus*.

When it comes to climate, biodiversity and short-term profit, we obviously face several policy and economy dilemmas and possible conflicts of interest. For instance, more costly offshore wind turbines may have less negative impact on biodiversity than developing cheaper wind turbine parks on untouched land. However, going offshore may increase spatial area conflicts with fisheries. In economic terms we may ask how to valuate and price limited resources such as land and terrestrial ecosystems when setting up cost balance sheets for new energy projects. Similarly, shortage of minerals, unless we increase our mining activities, may challenge further growth of green alternatives such as solar energy and batteries for energy storage in e.g., cars and ships.

The settlements on Svalbard are today dependent on hydrocarbon-driven power plants for production of electricity (local coal and transported diesel). It is really a contradiction that one of the most environmental sensitive areas in Norway is not supplied with greener and more renewable energy. We may turn this contradiction to an opportunity where Svalbard can be a destination for developing and testing of hybrid power plants combining solar and wind driven energy production with energy storage. The use of hydrocarbons is then limited to a minimum. Smart hybrid power plants that work autonomously without large transmission networks may be a natural next step powering societies and ships in a global scale with greener energy with less impact on climate and biodiversity. Why not start at Svalbard and then use this experience for further export of knowledge, products and services.

Climate adaption as well as novel concepts for the crossing of fjords and bays are increasingly important for the coastal economies. The majority of the world population lives in urban settlements close to the sea. We can hardly comprehend the cost of adapting these cities and land areas to increasing sea level of only few decimeters due to melting of land-fast ice. Again, the High North can be a good test destination for climate adaption.

ENABLING TECHNOLOGY

As we have seen we face both challenges and enjoy opportunities where technology and its use play important roles for human activities and corresponding impact on life and environment. There are many drivers for technology developments such as market needs, exploration needs (and dreams) accessing new and maybe extreme environments, as well as policy-driven rules and regulations. Game-changing technology is often provided through so-called enabling technologies. Enabling technology may be defined in different manners. Here, it is technology that can be applied to drive radical and thorough changes in public sector and industry inventions and innovations. For instance drivers for technology developments for improved mapping and monitoring of the oceans in the High North including the Arctic Ocean may be improved operability, access to remote and harsh environments (deep water, under ice, extreme coldness, etc.), long distance with limited ability to communicate, demand for improved coverage and higher resolution of data in spatial and temporal scales, reduced cost, improved safety, etc.

In this context we may categorize the following as enabling technologies with relevance for High North operations:

- Information and communication technology
- Nanotechnology
- Biotechnology
- Materials technology
- Big data cybernetics and data analytics
- Autonomous systems

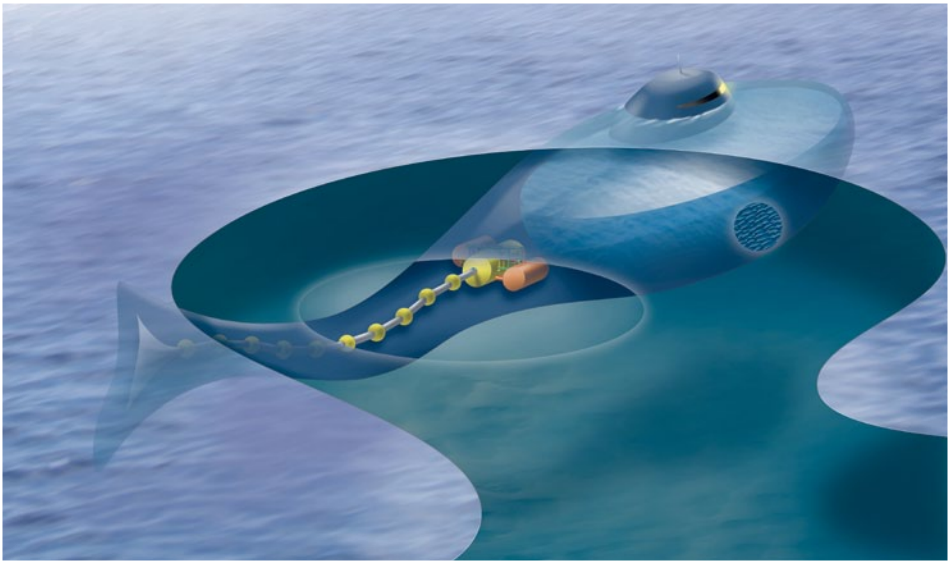


Figure 15.3: Being disruptive beyond imagination. Resistance in water can be reduced by intelligent materials that are able to sense and actuate on a micro scale, and a flexible body that can utilize dynamic pressure fields caused by waves, sea currents and the body itself for more efficient propulsion. Here we see an illustration of how a futuristic underwater vehicle may be inspired by whales.

Combined with fundamental knowledge fields such as mathematics, physics, chemistry, biology, computer science and engineering and by integrating disciplines and technologies we may get to a position where we can conduct research and innovations based on disruptive, game changing technology. What lies ahead may be beyond imagination. Examples could be to develop technology inspired by nature that are far more efficient and effective than today's solutions, e.g., applying multi-scale and distributed systems for sensing and actuation: micro-to-macro, see figures 15.3 and 15.4.

DOING THE RIGHT THING RIGHT

In order to meet the grand challenges, long-term and focused efforts are needed. Being heavily involved in one of the most successful research institutions in Norway—the Centre of Excellence scheme, I will exemplify how research is chasing impact and where enabling technologies and interdisciplinary knowledge will help us towards a better future. Probably, even more important is research-based education and training the next generation of engineers, scientists and decision-makers to have a holistic and sustainable mindset. In addition, where relevant we should drive innovation, which here means new methods, products or process that are valuable and applied. Important factors for innovation success are the authorization and mission given to the research team, or, put simply, *the license to create*.

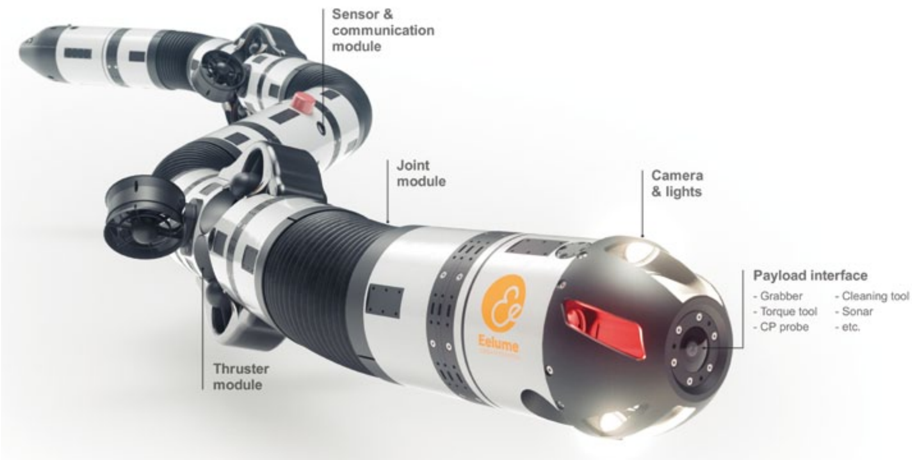


Figure 15.4: The Eelume flexible and hyper-redundant robotic solution for underwater inspection and intervention. An example of snake robotics, inspired by biology.

LONG-TERM RESEARCH CENTERS

NTNU AMOS – Centre for Autonomous Marine Operations and Systems is a 10-year Centre of Excellence (2013-2022) funded by the Research Council of Norway.[1] It focuses on fundamental research within marine technology, control engineering and marine biology, leveraging ground-breaking results on autonomous marine operations and systems. Research centers on fundamental research questions. NTNU AMOS has two research areas: a) Autonomous vehicles and robotic systems, and b) Safer, smarter and greener ships, structures and operations.

Both of these address long-term research efforts with relevance for the High North and Arctic regions. For instance, in Autonomous vehicles and robotic systems, we already defined in 2012 a research strategy for:

- How to develop autonomous sensors and sensors platforms—small satellites, unmanned aerial vehicles, unmanned ships and underwater vehicles, buoys—in air, sea surface and underwater environments for ocean mapping and monitoring.
- How to ramp up mapping and monitoring coverage 10 times with a cost of 1/10.
- How to enable public management agencies and industry to pilot and invest in new sensor and technology platforms.

Starting from these research questions we defined a targeted research project on Technology and methods for mapping and monitoring the oceans and Arctic regions, explained below.

[1] For further information see website: https://www.ntnu.edu/amos

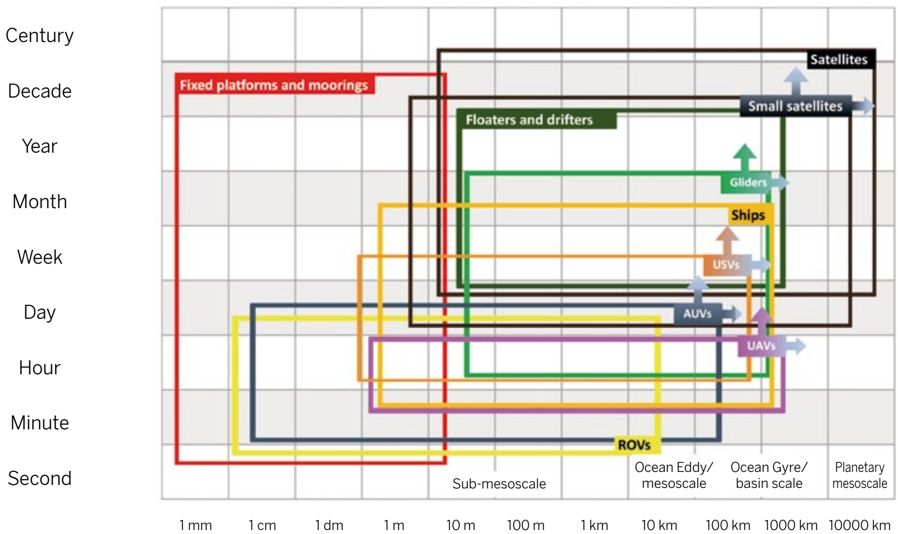
TECHNOLOGY FOR MAPPING AND MONITORING

Enabling technologies such as information and communication technology, autonomy and microelectromechanical (MEMS) systems provides new possibilities for the development of sensors, sensor-carrying platforms (figures 15.3 and 15.4), connectivity and big data analytics.

The sensor-carrying platforms operating from space to ocean space are:

- Underwater: landers and buoys, remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), gliders and profilers.
- Sea surface: ships, and unmanned surface vehicles (USVs).
- Air and space: satellites, unmanned aerial vehicles (UAVs) and airplanes.

Low-cost small satellites and in particular *nano*- (1-10 kg) and *micro*satellites (10-100 kg) carrying customized payload sensors and communication devices have opened up a step change in remote sensing and communication in polar orbits at altitudes of 450-500 km with about 3-6 hours for each pass. Swarms of satellites will provide a significant improved spatial and temporal coverage. At NTNU AMOS we have decided to launch two small satellites as a pilot: one for hyperspectral imaging of ocean colors and one for supporting Arctic communication. Environmental mapping and monitoring may be carried out by single platforms, swarms of platforms or combinations of several types denoted as *heterogeneous sensor-carrying platforms*. Each platform and sensor has various capabilities in terms of spatial and temporal resolution and coverage as seen in figure 15.5.



ROVs: Remotely Operated Vehicles; AUVs: Autonomous Underwater Vehicles; USVs: Unmanned Surface Vehicles; UAVs: Unmanned Aerial Vehicles

Figure 15. 5: Spatial and temporal resolution and coverage of different platforms (redrawn from Berge, Johnsen, and Cohen 2020).

Combining them creates a paradigm shift in terms of capabilities that may be 100-1000 times higher than the state-of-the-art technology only some years ago. The entailed increase in data harvesting also creates new challenges in the handling of big data sets. In order to take full advantage of the data and developing efficient adaptive strategies for sampling and measurements for the sensor-carrying platforms, refinement of models and co-simulation with numerical simulation models of the oceanography and ecosystems is essential.

From an Arctic perspective the environment can be characterized as remote and harsh for scientific operations and even more demanding during the polar night due to the darkness and extreme cold. Recent campaigns have also taught us the importance of light sensitivity for marine life and the effect of possible light pollution from ships. Use of robots as sensor-carrying platforms gives a far more precise picture of the ecosystem. Enabling technology and proper operational procedures may be the only way to reveal the processes in the Arctic Ocean. The spatial scale is enormous with large variability between seasons and over the years. This makes clear the importance of a prolonged presence and the potential for improved autonomous sensor-carrying platforms that are able to process the data onboard for improved real-time planning and re-planning of the operations. Our successful design and operation of autonomous platforms has clearly shown us the importance of multi-disciplinary teams.

Risk management is crucial for success of an operation, to avoid collisions, loss of vehicles, etc. This applies both to the environment and the operation of the sensor-carrying platform itself. As the autonomy level increases, more of the risk assessment and corresponding response must be done by the robotic platform itself. Improved sensors for situation awareness and more automated analysis of sensor data locally enable the sensor-carrying platforms to cooperate, optimize and re-plan the mission. Situation awareness is here defined as: perception of the elements in the environment; comprehension of the current situation and; finally, projection of the future situation. Operating in extreme and partly unstructured environments makes Arctic operations similar to space operations. Operating in the High North and Arctic regions demands technological solutions that have extreme capabilities and are effective, efficient and resilient.

For the High North and Arctic regions, a holistic approach is of vital importance and urgency. Knowledge and technology will enable us to develop sustainable solutions. Interdisciplinarity between disciplines such as technology, natural science and the humanities are essential success factors. There is no room for arrogance and ignorance. Thorough knowledge, wisdom and courage, combined with political leadership, are needed to solve the global challenges, and avoid a situation where promising solutions thought to be part-of-the-solution instead become part-of-the-problem.

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CHAPTER 16

CHOICES, CHOICES

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THE CHOICES WE MAKE

The future of the Arctic Ocean is a matter of human choice. These choices can be big ones at a high policy level, such as whether to open the Arctic Ocean to commercial fishing or oil and gas activity. But many of the choices are small ones. Each time I choose to start my car, turn on a light, or get on a plane, I am responsible for additional greenhouse gas emissions, which all contribute to further melting of Arctic sea ice.

So far, humans have shown little or no inclination to make choices that will keep the Arctic Ocean cold, icy, and largely free from direct human influence. Instead, individually, industrially, and nationally we choose to continue warming our planet. Individually, my choices affect the Arctic, try though I might to justify plane flight after plane flight on the grounds that I am working to conserve the environment. Ironic at best. Industrially and nationally, we promote Arctic resource development in the forms of mining, shipping, tourism, and fossil fuels. The last of these is another irony, as fossil fuel exhaust warms the Arctic, making access easier, spurring more fossil fuel extraction. Some even see this as opportunity rather than warning.

There are some bright spots, here and there. Ten countries agreed not to start commercial fishing in the high seas of the Central Arctic Ocean, following similar policies in the Arctic waters of the United States and Canada. The rationale is that we simply do not know enough to fish responsibly and sustainably, so it is better not to start until we do. Some companies have pledged not to use Arctic shipping routes, at least for the time being, until those routes can be taken without undue risks to Arctic ecosystems and cultures. Since there are few fish in the Arctic Ocean and well-established shipping routes elsewhere, these are modest choices, but welcome ones, nonetheless. If the future of the Arctic Ocean will be shaped by human choice, and if we do not wish to see those choices made by default and in ignorance, what is it that we would like to see? The

Photo 16.1: Dovekies *(Alle alle)* off the Svalbard coast in summer.

answers, of course, vary greatly depending on who is answering. Vladimir Putin sees a vigorous display of Russian economic and military strength in the Arctic. China sees resources and opportunity, such as the Polar Silk Road. Conservationists see a chance to protect intact, abundant waters rather than remnants of species and habitats. Indigenous peoples see their homes and the future of their ways of life. Not all of these visions can exist at the same time in the same places.

THE ARCTIC I WOULD LIKE

What I would like to see is an Arctic Ocean much as it was in the late 20th century. Covered in sea ice much of the year. Home to healthy populations of marine mammals, seabirds, and more. Supporting traditional cultures as they are practiced and as they evolve through local initiative and leadership. Site of a modest amount of industrial and commercial activity, providing economic opportunity for Arctic peoples without unduly risking those healthy wildlife populations.

And I would like more. I would like sensible, precautionary industrial policies, similar to that of the Central Arctic Ocean Fisheries Agreement. Accounting not just for the expected effects of a single activity, but giving attention to the long-term, cumulative effects of an increasing human footprint on ecosystems and species that so far have largely been left alone. Recognition of the high degree of uncertainty in our understanding of the Arctic Ocean, and a concomitant willingness to keep risks low by not constantly pushing the bounds of what is possible. The resources will be there tomorrow, too. They needn't be grabbed today while the state of our knowledge and technology means we can only hope we do not destroy something we have barely gotten to know.

Most of all, I would like to see an Arctic where Indigenous and local peoples can determine their own futures. Throughout the 20th century, and in many areas for far longer than that, Indigenous and local cultures have been buffeted by the many winds of colonialism. Missionaries, educators, whalers, traders, prospectors, explorers, scientists, bureaucrats, industrialists, and more have come north in search of their own desires and fulfillment. Some have had lofty motives, to improve the lives of those already living in the Arctic. Others have seen existing residents as irrelevant or even as impediments to their goals. All have created legacies with aspects good and bad. Few if any have contributed to the ability of Arctic peoples to choose their own destiny.

Instead, under the guise of raising standards of living and human development, Arctic residents have had to conform more and more to the rules and expectations of mainstream societies. Native languages replaced by national languages. Traditional hunting

Photo 16.2: Closing ceremony of the Inuit Circumpolar Council's 2010 General Assembly in Nuuk, Greenland. Held every four years, the General Assembly is where delegates come together to work for the Inuit peoples' common good.

and fishing patterns forced to conform to the dictates of a wildlife management system developed for recreational and commercial users. Seasonal cycles of land use and activity pushed aside for a wage economy that runs by the clock and the weekday calendar. Educational systems that teach facts and values from afar but not the skills, attitudes, and knowledge needed to thrive in the Arctic.

WHY I TOO WANT A VOICE

I do not pine for the Arctic Ocean of some romantic yesteryear. In the old days, life was difficult, life expectancy low, and small isolated societies were not a carefree paradise of equality and justice. But neither were they miserable, brutish existences barely sustaining life. They were human communities, with the flaws and graces of all human communities. The arrival of the modern world has, as elsewhere, brought its anxieties and problems, and also its conveniences and improvements. A friend of mine, a late Elder from Utqiaġvik, Alaska, said he had grown up in poverty and had no wish to return to it, nor to see his grandchildren do so. And he was also a staunch advocate for his community's ability to make its own choices.

At heart, being in control is a matter of having the ability to make mistakes without someone stopping you. Many policies that appear to move in the direction of Indigenous and local self-control come with strings attached. Someone else will be watching, with the power to approve or deny the choices made by Indigenous and local organizations. Ostensibly, these decisions to approve or not are based on established principles of good governance, sound science, and other watchwords of modern societies. In other words, this oversight power is intended to prevent people from having to live with the consequences when they make poor choices. In practice, however, such power is often used to promote conformity to the dominant paradigm, rather than in acknowledgment that there are different ways to see the world.

Perhaps the essential problem is an inability to accommodate different ways of seeing the world. Traditional views of the relationship between humans and animals are very different from scientific views of that relationship, with major consequences for wildlife management and other policies and practices. Creating a system that can accommodate both views is not simple. As mentioned earlier, there are many visions for the future of the Arctic Ocean. Some are irreconcilable. We cannot have confidence in the continued abundance of Arctic marine mammals if the threat of a major oil spill remains hanging over us. Other differences are more a matter of perception. Residents of northern Alaska favor oil development for the economic benefits it brings, and at the same time revere the bowhead whale that is at the center of their traditional way of life. They may well see the same conflict between those aspirations that I do, but decide that the risk is worth it.

While recognizing the importance of Indigenous rights, I do not necessarily believe that whatever Indigenous and local peoples want is always for the best. Any group of humans is perfectly capable of shortsighted selfishness, perfectly capable of ignoring evidence and experience from elsewhere, perfectly capable of succumbing to the lure of the shiny and new instead of the tried and true. So, while I advocate for Arctic self-determination in their own affairs, I do not want to see pan-Arctic industrial and governance policies set by any single group or interest.

And this is why I cannot quite let go. I, too, would like a say in the decision about whether to drill or not, whether to create major shipping routes or not, whether and how to regulate hunting or fishing. I would like to be involved in the choices that will shape the Arctic Ocean, even if I am only a minor voice whose standing is based solely on the idea that I care about the Arctic Ocean. I do not live on the Arctic coast (though I once did for a few years), I do not own or use Arctic resources, I have no position of authority to make decisions about the Arctic Ocean. If bowhead whales disappeared, I would be sad, but my life would suffer no material consequences. Yet still I care. My friends would suffer. My heart would ache. The world would be poorer. And so, I assert myself in Arctic choices.

Photo 16.3: Bowhead whales *(Balaena mysticetus)*, a cultural mainstay in Arctic Alaska.

THE ARCTIC I EXPECT

So much for the Arctic I wish to see. The Arctic I expect to see is one where we follow today's trends. Sea ice diminishes further, and at some point in my lifetime the Arctic Ocean is considered "ice free" on a late summer day when the melting has undone all that winter could do. Industrial shipping increases, to Arctic destinations such as the Yamal Peninsula and through the Arctic to connect the industrial and population centers of Europe, Asia, and North America. Commercial fishing eventually begins, most likely in coastal and national waters first, as fishes move northwards and the barrier that is sea ice retreats. Oil, gas, and minerals are developed wherever they are found, pushed by a combination of local economic dreams and corporate power to influence governments. All the right things are said about protecting the Arctic marine environment, and by a series of small choices and actions, the Arctic Ocean is converted into just another ocean, diminished piece by piece as we lose sight of what it once was, what it could be.

Those small choices involve each of us. Marine plastics are a problem in the Arctic, far though it may be from most sources of such trash. How we use and discard the ubiquitous plastics of modern life is a choice we make, individually and societally. I am no better in this regard than I am with regard to my carbon footprint, though I make modest efforts to reduce, re-use, and recycle. It is hard to see the harm in any single decision, making it all the easier to keep doing what we have gotten used to doing, as species and habitats decline. Those declines are slow enough that we hardly notice, further separating our actions from their consequences. And the Arctic is far enough from the majority of humans on the planet that the consequences of their actions are too remote to be of much concern, faced as they are with the demands of their own lives and home regions.

The challenge then is not simply to create a few national and international policies that will take care of the Arctic Ocean. We can take a precautionary approach to resource development, as we are currently doing for Arctic Ocean fisheries. We can pass rules about Arctic ships and shipping, as the International Maritime Organization (IMO) has done with the Polar Code, Bering Strait shipping routes, and more. These are important steps, and worth taking, but they don't address every issue: the plastic waste found in every fish in the Arctic, the number of ships or the hazards of the cargoes they carry, or the build-up of pollutants to which each passing vessel adds. Recognition of Indigenous rights is a welcome step, as has been done in North America especially. But without the capacity to escape the dominant economic and political paradigm, Indigenous rights are often just a change in the individuals sitting in the seats of power and administration.

In addition to strong national and international policies, we need to address the choices we all make that create the demand for Arctic resources, the choices we all make that result in greenhouse gas emissions warming the waters and melting the ice. Perhaps we cannot get everything on my wish list but getting some of them would be better than getting none. I would like to think that we do not need to change the entire world system to protect the Arctic, but we certainly need to recognize the symptoms of failure that manifest themselves in rapid change to a remote part of the world. Less sea ice means more sunlight is absorbed, creating more warming. Thawing permafrost releases greenhouse gases, creating more warming. Melting of glaciers and ice sheets raises sea level, causing havoc around the world. Even with vigorous action to prevent further climate change, the Arctic will not soon if ever be restored to the way it was only a few decades ago. This is hardly a world on the right track.

THE ARCTIC I FEAR

Which brings me to the Arctic Ocean future I fear. It is easy to think up doomsday scenarios, such as a major war taking place in the Arctic or a resource-grabbing free-for-all when governance breaks down for some reason. Those strike me as unlikely, and I don't think there's much I could do if society has reached such a dysfunctional place. Instead, the Arctic Ocean I fear is one where we accept as normal the idea that Arctic sea ice is seasonal or non-existent, that Arctic resources should be developed wherever and whenever possible, that Arctic peoples should get on board with development and

Photo 16.4: Inuvialuit girls learn to fish with their grandfather. Mackenzie Delta, Northwest Territories, Canada.

assimilation and put millennia of tradition into a museum or even further out of sight and mind.

Unfortunately, the Arctic I fear is not all that far from the Arctic I expect. The difference is that in the Arctic I fear, all meaningful opposition has vanished, and no one is fighting for the Arctic I would like to see. I am not alone, for now at least, in hoping for an Arctic Ocean with sea ice, where migratory species can go throughout the year without encountering industrial infrastructure and activity. An Arctic in which Indigenous practices, knowledge, and values remain alive and vital. An Arctic that remains distinct from the rest of the world ocean and that continues to inspire and astonish us.

That is the choice that remains: to contribute to the plunder and destruction of the Arctic we know, to stand by and watch others plunder and desecrate, or to fight for what is left and what can still be. I choose to fight.

CHAPTER 17

NEW APPROACHES ARE NEEDED TO ADDRESS DRAMATIC CHANGE IN THE BERING STRAIT REGION

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Wide ranging and profoundly disturbing: these words describe the extraordinary changes happening in the Arctic region. The Arctic of today does not resemble the Arctic of fifty years ago, and the Arctic of 2070 will be different still, based on everything we know now. Warmer temperatures on land and in the ocean, retreating sea ice and glaciers, thawing permafrost, rapidly changing ecosystems, range expansion of novel species and stress in native species, changing ocean chemistry, and altered seasons all contribute to significant alteration of a region in an extremely compressed timescale. At the same time, globalization and the increasing international interest in the region add new pressures for access, development and geopolitical positioning in the Arctic. Concerns about the implications and impacts of that intensified engagement generate even more anxiety about the transformation to a brand new Arctic in the twenty-first century.

These changes are undeniable, and they are accelerating, as has been well documented by numerous studies, scientific papers, Indigenous knowledge and by personal accounts from the people of the Arctic describing the changes they are witnessing and how their lives have been impacted. All these sources agree that the change and the impacts are unprecedented and threaten the health and safety of communities now and in the future. Has this documentation changed the way in which decisions are being made to prepare for the future? In my opinion, only to a very limited extent.

GOVERNANCE VACUUM

Why has there been so little action directed toward adapting to the realities of a changing Arctic and the necessity to prepare for future conditions that will alter economic livelihoods, transportation systems, cultural practices, and communities? I believe it is

Note: This essay reflects the author's own opinions, not the position of the Belfer Center.

not for lack of concern or even lack of trying. It is due in large measure to an absence of sufficiently adapted governance structures that can appropriately gather, incorporate, evolve, and then fund the multi-layered solutions that will be successful.

Most Arctic forecasting efforts attempted by governments, researchers, and planners conclude with reports describing some of the anticipated changes and broad recom-

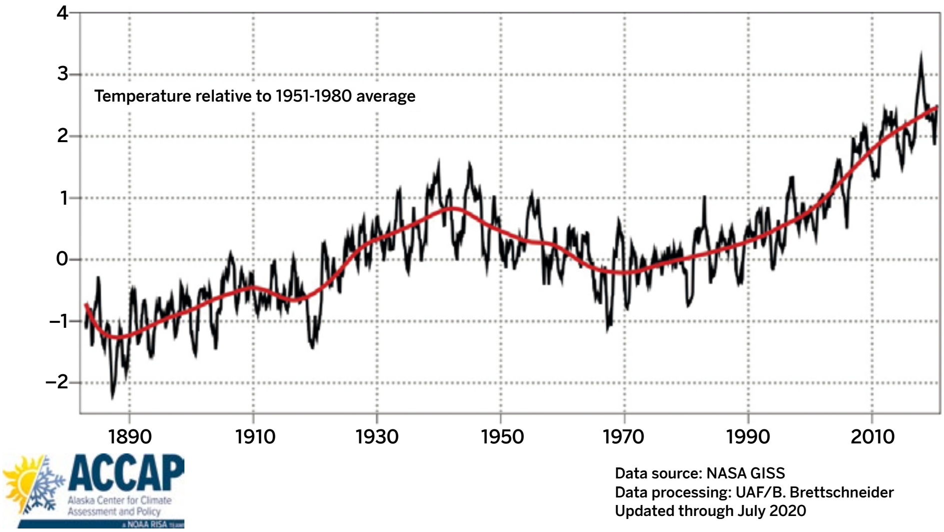

Figure 17.1: Arctic (poleward of 65 N). 12-month running average temperatures, 1882-2020.

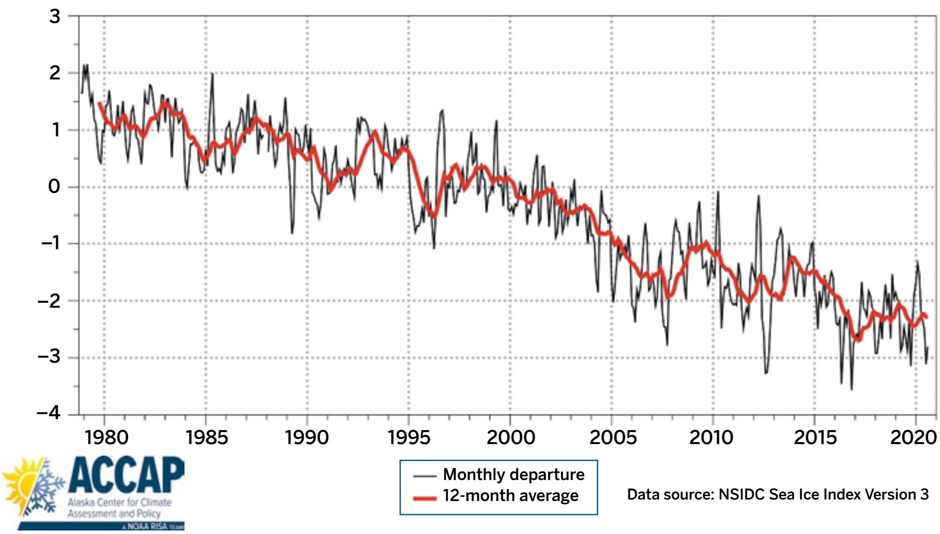

Figure 17.2: Arctic-wide sea ice monthly extent. November 1978 to August 2020.

Photo 17.1: Shoreline erosion in Kivalina, Alaska.

mendations about the need for more research and more funding by governments. It certainly is true that more research and more funding would be helpful. That is not enough, however, to accurately or completely understand the implications of those changes, or to effectively organize the challenging work of preventing some of the most negative outcomes. What is needed are new methods to evaluate and then implement the adaptation measures needed for a sustainable Arctic and its people.

Currently, most government funding and agency approaches to the dramatic changes in the Arctic are modest and incremental. For example, communities that are highly vulnerable to coastal erosion get assistance in building sea walls with a design life of a few years. Even those communities that have been identified as candidates for relocation find it very difficult to obtain support for longer-term solutions like financing new community construction, or for other approaches to help people transition to safer locations (like the Canadian program to pay for individual moves). Needless to say, these decisions are extremely difficult for many reasons, such as a lack of consensus at the community level, disagreement about alternative sites, no established state or federal program that is responsible to assist before a disaster happens instead of after the fact, in addition to lack of funding.

DIFFICULT DECISIONS

The village of Shishmaref is an example of a community in Northwest Alaska that has voted several times to move, and then not move, and then move again. Shishmaref is a traditional Inupiaq village of approximately six hundred people on Sarichef Island, just north of the Bering Strait. Hundreds of feet of shoreline, houses and parts of roads have been lost, due to coastal erosion and thawing permafrost. The US Army Corps of Engineers has rated it extremely vulnerable, and has tried unsuccessfully to construct permanent barriers that could be sufficient protection for the village. When I visited Shishmaref over a decade ago, I attended one of the town meetings discussing the potential relocation. It was heartbreaking to hear the stories of people who had deep connection to a place generations had called home—the only place they ever expected to raise their families. However, the powerful fall storms were eating away their shorelines, year after year, eroding the coastline. The late onset of freeze-up and absence of sea ice left them unprotected from the pounding waves of the Chukchi Sea just a few feet from their homes. It is no wonder that moving a village creates such difficult emotional divides, particularly when there is no governmental program to provide the kind of assistance needed for planning and designing or funding a managed retreat or relocation, until after a disaster happens.

Similarly, projected increases in shipping and potential industrial developments stimulate many conversations about the need for more ports and more support infrastructure in key locations. In some areas of the Arctic, like the Bering Strait region, that infrastructure is minimal. Sometimes the discussion focuses on promoting those activities as economic opportunities; sometimes the focus is on preparing for potential accidents and disasters, and lately, the focus is on national security. All of these discussions are important in building more awareness about the challenges presented by changing conditions. However, the more difficult questions about assessing the relative positives and

Photo 17.2: Erosion in the village of Shishmaref, Alaska.

negatives of alternative sites for projects or evaluating the potential impacts of new development on traditional cultures and local environments are often considered too politically and culturally difficult to discuss openly. Moreover, many different entities have roles in the decision process, each with their own method for seeking input, focusing on one part of a project at a time. Meaningful opportunity to involve and respect the perspectives of the people most impacted by decisions is essential, but rarely done in ways considered satisfactory. It is challenging to develop a process to identify feasible and sustainable adaptation options, evaluate them, and then develop a consensus among the essential stakeholders and relevant decision-makers. However, that is exactly what is needed, given the scale of the decisions that need to be made.

THE BERING STRAIT REGION

The Bering Strait Region is a great example of an Arctic region where these questions are highly relevant and critical to its future. The Bering Strait is one of the most valuable and vulnerable places in the Arctic today. The narrow strip of water between Alaska and Russia, 51 miles wide, is a major wildlife corridor for countless marine mammals, birds and fish that migrate through the Strait twice annually. As a link between the Bering Sea and the Chukchi and Beaufort Seas, migrating marine mammals, waterfowl and sea birds,

Map 17.1: The Bering Strait region.

and other wildlife are wholly dependent upon the Bering Strait to get to the historically productive Arctic waters for mating, nesting and feeding in spring and summer. The Indigenous Peoples in the region, both in Alaska and in Russia, possess a vibrant cultural heritage based on subsistence harvest. They have a vital interest in the health of the ecosystem and the sustainability of the species they have depended on for centuries.

Concurrent with this environmental change, the Bering Strait is becoming a major shipping lane for vessels transiting between the Arctic and the North Pacific, with traffic increasing, particularly between the Northern Sea Route and Asia. From cruise ships to LNG tankers, increased vessel traffic in this narrow passage raises concerns about the potential for maritime accidents such as oil spills, interference or injury to whales and other marine mammals from ship strikes and disturbance, and disruption of subsistence hunting and activities. These risks are magnified by increasingly unpredictable and extreme weather conditions and the lack of nearby facilities for intervention (rescue, response, clean-up, etc.).

The challenges posed by increased ship traffic have generated attention from governments, industry, local residents, and environmental organizations, prompting efforts to explore interim steps to address these risks. Examples include the Alaska Port Access Route Study process; the Waterways Safety Committee; a bilateral agreement between the US Coast Guard and Russian agencies on ship routing; the informal cooperation between Russia and US Coast Guards to open lines of communication through the Arctic Coast Guard Forum; the mandatory Polar Code adopted by the International Maritime Organization and IMO's approval of voluntary two-way routes on both sides of the Bering Strait which was jointly proposed by Russia and the United States, as well as three Areas to Be Avoided in the Northern Bering Sea (around Nunivak Island, St. Lawrence Island, and King Island).

However, very few of these efforts address the broader questions of long-term impact, or how to best structure the management of international shipping through the Bering Strait, or to how to effectively involve and empower the tribes and local communities whose subsistence activities could be impacted. Their participation in the choices being made about development, investment, regulation, and coordination of response is essential.

PREVIOUS EFFORTS TO COORDINATE AND ALIGN

On January 21, 2015, President Obama signed Executive Order 13689 titled "Northern Bering Sea Climate Resilience Area" creating a special coordinating entity to do just that in response to requests from the Bering Sea Elders, Kawerak and Alaska Village Council of Presidents (the Alaska Native regional tribal organizations representing tribes in the area). The Order created "The Task Force on the Northern Bering Sea Climate Resilience Area" and the "Bering Intergovernmental Tribal Advisory Council" in order to bring some focus to federal agency decision-making and enable local voices to be heard more effectively. Unfortunately, it was formalized late in the Obama Administration and as a result, it was barely formed before it was abolished by the Trump Administration. Very little can be said about its utility since it did not have the opportunity to work as designed, but both the agencies and the Alaska Native tribes demonstrated an eagerness to establish the structures included in the Executive Order.[1]

The need continues for such an entity to bring focus to the key issues, to incorporate the local understanding and Indigenous knowledge, to reflect the values of those who stand to either benefit from wise decisions or suffer the consequences of mistakes, and to better understand and bridge the chasm between differing goals for the future of the Bering Strait region.

In 2019, Senator Lisa Murkowski introduced a bill titled "The Arctic Policy Act" which included language to establish a similar coordinating entity. The legislation also addresses other issues including Arctic research and policy, but this particular provision should prompt more discussion about how to create a new model for evaluating, engaging, and managing the dramatic changes in many places in the Arctic. Without an overarching structure, it is difficult to understand and evaluate the impacts of multiple projects or their cumulative impacts because it is difficult to identify and include all of the relevant participants who can add information and insight to such deliberations on a consistent basis. This includes the local and Indigenous knowledge holders who have unique and essential understanding to offer, and the scientists who have done research in the region over many years. Unfortunately, the status quo results in piecemeal decisions that may or may not be compatible with other decisions made by other agencies, organizations or commercial interests.

In some regions, governments use regional planning to attempt to bring those many factors, relevant information, and competing alternatives into a more cohesive vision and strategy. In some cities and countries this approach can work effectively. However, elsewhere there are fewer resources available for comprehensive planning and less confidence in its value as a way to build consensus, so it is rarely used, and that is the case in Alaska. Another barrier to effective planning and implementation is the lack of systematic coordination by the federal and state agencies that have relevant jurisdiction and responsibilities. The Arctic Executive Steering Committee which was created by an Executive Order in 2015 ("Enhancing Coordination of National Security Efforts in the Arctic") was beginning to address this situation, but it no longer meets. Fortunately, one of the subgroups, the Community Resilience Working Group does convene

[1] An executive order is a means of issuing federal directives the Unites States, used by the President of the United States, that manages operations of the federal government.

calls for periodic updates. The State of Alaska once had the Department of Community and Regional Affairs, and the Alaska Coastal Management Program, both of which were vehicles for strengthening opportunities for the local, state, federal, regional, tribal and private interests to share information and resolve differences. Without these structures for collaboration, there are vacuums to be filled at both the state and the federal levels.

In addition to the need for a structure to improve collaboration and meaningful deliberation about major decisions that must be addressed in a time of rapid transformation, it is essential that projections about alternative futures be based on reliable, relevant information. Many activities that are impacted by a changing climate, from fisheries management to resource extraction, are regulated by agencies relying on information that may be outdated. For example, the last time Alaska updated its Land Atlas, on which engineers base their construction designs, was in the 1980s. Updating information is crucial; changing conditions (increasing permafrost thaw and rain or snow events) impact the design and construction of roads, airports and buildings. There are other examples of systems that are slow to incorporate the projections of climate change which are available from reliable scientific sources. For example, a village threatened by coastal erosion may find it more difficult to make a decision to abandon a vulnerable site if the range of possible damage from storm surges or permafrost thaw is uncertain. That un-

Photo 17.3: Permafrost thaw and shoreline erosion in the Bering Strait region.

certainty can stymie the tough decisions that could be considered in light of the rate of change being experienced in the region.

The Alaska Center for Climate Assessment and Policy at the University of Alaska Fairbanks is doing a wonderful job of providing information and downscaling climate models. But the range of possible futures is large. A recent Statewide Threat Assessment prepared for the Denali Commission by the University of Alaska Fairbanks and the US Army Corps of Engineers is a good example of an effort to combine information about climate threats to communities in Alaska. But whose responsibility is it to gather the relevant information from a variety of sources, to prepare alternative scenarios to show future options clearly, and to facilitate the discussion and decision process? How will this be possible, from both financial and organizational points of view, as more communities are at risk from the dramatic changes and as more infrastructure development evolves? What venue exists for discussion about the benefits and realities of alternative approaches?

These problems are not unique to the Bering Strait region, as many communities across the world are attempting to creatively address the climate change threats to their homes and their economies. From Venice to New Orleans, similar challenges are confronting people and their institutions. Many governments struggle with the complexity of assuring meaningful stakeholder involvement and obtaining participation from the multiple jurisdictions that have overlapping governance authority and responsibilities. In urban areas, those can be cities, counties, airport and port authorities, metropolitan water districts, and others. In rural Alaska they include tribes, cities, boroughs, Alaska Native Corporations, state and federal agencies, and, in some instances, international entities. The unique aspects of the Bering Strait region make this a place where the combination of urgency and uniqueness call out for a new approach sooner rather than later.

POSSIBLE PATHS FORWARD

It is time to consider and evaluate alternative structural and procedural approaches to improve how we handle the new realities of a rapidly shifting climate, landscape and seascape, and to develop tools that could be useful to successful adaptation. Effective solutions to these challenges will require a willingness to experiment with approaches that are not currently available. Too much is at stake to assume that the current decision-making structures and processes are sufficient.

Here are a few ideas to consider in addressing these challenges in the Bering Strait region:

1. Designation of specific areas that are vulnerable to significant climate change risk as "areas of elevated attention," as was done for the Northern Bering Sea

Climate Resilience Area. Such a designation would trigger the creation of a multi jurisdictional, inclusive, coordinating committee to bring the relevant stakeholders and decision makers together. Although this region is not the only part of the Arctic that could benefit from this approach, it is one where there was sufficient local, tribal and federal agreement to try a different coordination process to improve and align decisions. Much could be learned from doing this in such a challenging and important area.

2. Re-engagement of the Arctic Executive Steering Committee by agencies that have management responsibilities in the region, to provide a more cohesive, if not completely comprehensive, assessment of what federal and state agencies are doing in the region, and share that information with the many other groups, communities, and decision makers who could benefit from that analysis.
3. Formation of a coordinating hub by Alaska tribes for Indigenous knowledge holders willing to work with scientists doing relevant research in co-producing the needed information for long-term decisions in resource management.
4. Preparation and dissemination of better guidance to the research community on how to conduct research collaboratively in partnership with communities, and how coproduction can strengthen and add credibility to their research results. Canada's Arctic Net could provide a template for the kind of collaboration that links user needs with research investment.
5. Reconstitution of a coastal management program by the State of Alaska that could be a central point of contact and communication for state, federal, local, tribal and business interests to jointly focus attention on the available tools to reduce risk and support adaptation.

Though there are likely many more initiatives that could be undertaken to strengthen effective and coordinated adaptation, these recommendations are provided to prompt discussion and analysis of alternatives that might be helpful in the Bering Strait region, and perhaps elsewhere. Adapting resource management practices and developing strategies to reduce risk to communities and their livelihoods will require trial and error. The transition will be characterized by efforts that will be successful and others that may be considered "lessons learned." That is to be expected, but it is imperative that we create new and effective ways to reach consensus and adapt to the rapid changes in the region. Most importantly, this effort needs to happen soon and in an expedient matter, as not only will these problems not resolve themselves; they are building in size and demand immediate attention. I believe that the residents and researchers of the Arctic will rise to these challenges if the resources can be found to make it possible, and if everyone works together toward common goals.

CHAPTER 18

TRADITION CONNECTS THE PAST, PRESENT, AND FUTURE OF THE ARCTIC OCEAN

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THE PERSISTENCE OF TRADITION

People have lived on the shores of the Arctic Ocean for tens of thousands of years. During this time, glaciers and ice caps have come and gone, sea level has fallen and risen, the Bering Land Bridge has turned into the Bering Strait, and people have adjusted and adapted. As is the case elsewhere, too, those adjustments have not always been easy or painless in the Arctic. Greenland, for example, was settled some 4,500 years ago, but those peoples died out, and the island was not re-settled for a long time. Migration, starvation, and conflict have never been far away. In recent centuries, new arrivals have brought new ideas, tools, religions, behaviors, diseases, and more to Arctic shores. Once more, Arctic peoples have adjusted and adapted, not always easily or painlessly, but they have persisted. In some locations, today's settlements are built on or next to the remnants of sod houses and other constructions of the past, vividly illustrating the continuity of human presence in the Arctic. In other places, the ancient human footprint is too faint to be seen directly, but can be recognized in place names, rituals, and other aspects of cultural memory and practice.

When we think about where the Arctic Ocean is going, it is useful also to think about the journey that people have taken with the Arctic so far. Today's changes are big and fast, but there have been big and fast changes before, too. The arrival of Europeans in the Bering Strait region, for example, caused tremendous social and ecological upheaval in the space of a few decades (e.g., Bockstoce 2009). One lesson from past to present is the persistence of tradition as a way of understanding and respecting the Arctic and its environment. Not all traditions have survived intact, and those that are still practiced are the result of determined efforts by individuals who might more easily have given up on the old ways. Songs, dances, stories, and rituals may be recorded in an archive, but they only live when people continue to sing, dance, tell stories, and practice their rituals. We may not know exactly where the Arctic Ocean is going, but we can hope that the tradi-

Photo 18.1: Walrus haulout on a shore.

tions of Arctic peoples continue to be a large part of the story, and we can do our best to help that happen.

In this essay, we look at coastal communities of Chukotka, Russia, in the Bering Strait region as an example of the persistence, fragility, and importance of traditional practices and knowledge on Arctic shores. In this case, "we" refers to Eduard Zdor, Chukchi from the village of Neshkan who has long been involved in research and marine mammal co-management in his home region, and Henry Huntington, an American researcher of European descent who has been living and working in Alaska for over three decades.

The Bering Strait region's culture has a millennia-deep human history and was built on direct and deep dependence on walruses, seals, and whales (Fitzhugh and Crowell 1988, Dikov 1988). The toggled-head harpoon and skin boat were great inventions of the Old Bering Sea culture and contributed to the sustainable traditional subsistence of the local communities. The Chukchi and Siberian Yupik of what is now the Russian Far East established their interactions with walruses on the basis of comprehensive practical knowledge. This knowledge included customs and rituals governing relationships with walruses that contribute to safe and effective hunting, healthy processing and storage of walrus meat, and the distribution of hunting products. The accuracy and practicality of knowledge was obtained using methods such as observation, information gathering, experiments, and their interpretation. According to the Chukotkan Natives' animistic beliefs, walruses were the same as people. During the 20th century, a significant part of traditional knowledge was affected by acculturation, notably Soviet policies but also post-Soviet events. However, largely due to the fact that traditional subsistence has retained its importance for local communities, traditional knowledge has remained in demand. The Bering Strait region is not unique in this respect, and its lessons apply equally well wherever Indigenous Peoples continue to practice their ways.

WALRUS HUNTING IN CHUKOTKA

In the case of walrus, hunters constantly and scrupulously observe the animals and their habitat. This knowledge provides perspective and interpretation of these animals, built on a combination of interactions, observations, and beliefs. The production, preservation, and transfer of subsistence-oriented knowledge are done through practical actions and oral traditions. Walrus hunting is important for communities in terms of providing food. The proportion of walrus meat is at least 50% of the total harvest of marine mammals for Chukotkan coastal communities.

There is another significant impact of walrus hunting on communities, due to the fact that this is a collective activity. This means that knowledge is transferred not only from fathers and uncles to sons and nephews, as in most types of traditional subsistence, but

Photo 18.2: Pulling out harvested walruses.

this is a type of men's club in which all participants in the activity are producers, custodians, mentors, and recipients of knowledge. This is the main difference between cooperative walrus hunting (and relatively rare whale hunting), on the one hand, and individual seal hunting, on the other hand. The fact that producing traditional walrus knowledge is a collaborative process provides its sustainability beyond any one individual. The search for walruses, hunting, butchering, processing, distribution, and transportation of hunting products are accompanied by rules and traditions that give rise to a complex and comprehensive process of knowledge production. Traditional knowledge, the skin boat, and the toggled-head harpoon became the cornerstones of the viability of local communities.

Modern Chukotkan hunters continue to use traditional hunting methods, adapting technical innovations to subsistence-oriented activities. Hunting patterns typical of individual settlements are generally the same as they always have been. For example, boat owners decide when to hunt, as in the old days. His decisions are based on traditional knowledge of the biology and behavior of marine mammals, seasonality, weather and sea ice conditions, as well as permits from federal authorities. The captain of the boat, usually the helmsman, decides where to go and which group of walruses—on ice, on water, or on shore—to hunt. He also appoints positions among team members. In fact, it is a complex process in which traditions, heredity, skills, and luck are mixed. There is no strict specialization among crew members: some are better at shooting from rifles, some are more accurate with harpoons and can throw them farther, and some are just sailors who prepare the boat, row, butcher animals, and do the other hard tasks of a sea hunter. Each hunter gradually tries each position in the team and, over time, all hunters take their places in the boat.

The same long-term and gradual approach is used in training a sea hunter. It is important to start learning from childhood. Boys have typically been involved in hunting since about seven years of age. At this time, they are more or less independent enough to be in the boat safely, observe the hunt, and perform light auxiliary work. Around the ages of 10 to

Photo 18.3: A culinary and cultural tradition. *Left, kymgyt* walrus roll; *right*, walrus skulls at the site of the Walrus Heads festival.

12, boys kill their first seal independently. Gradually, adolescents are drawn into the everyday life of hunters, gaining knowledge and skills. The core teaching strategy practiced by senior hunters is, "Observe and do as I do." At the end of the adolescent period, the young hunter knows how to prepare the boat for the hunting season, make and repair equipment, row, steer the boat, throw a harpoon, shoot, determine the weather, sea, sea ice, and location of marine mammals, and also the protocol of actions in extreme situations.

BELIEFS AND RITUALS

Most Chukotkans adhere to their traditional beliefs, which are animistic. Since Christianity complicated the religious pattern of the post-Soviet Chukotka Indigenous community, it is likely that people have performed shifted and mixed rituals devoted to interacting with walruses, regardless of their religious affiliation. However, even today, spiritual and ritual ties to the Earth and animals are a condition of local community nutrition and well-being.

The main motivation for observing the rituals is the assertion that the success or failure in sea hunting depends on the interaction between hunters and masters (i.e., spirits). Spirits can be friendly to the hunter or, conversely, interfere with the hunt. This motivates hunters to establish relationships with masters by observing rituals. In appearance, the ritual looks like a *sharing ceremony*. Hunters either share food and tobacco with spirits before the hunt, or return pieces of the internal organs of the harvested walrus to the sea after the hunt. The ritual is not a simple act of sharing, however, but is rather a process of mental preparation, a way for the participants to gain self-confidence and team spirit. The *exchange ceremony* is accompanied by a conversation with the spirits. Before going to sea, the ceremony sets the hunter's mind at ease for a successful and safe hunt. In a ceremony after a successful hunt, a conversation with the spirits is filled with gratitude that they shared food with the hunters, allowing the hunters to provide their relatives with the means of survival. On the whole, both the ritual and the tradition of sharing were built by the *circle of food sharing*.

The performance of the ritual gives the hunters a sense of certainty: if everything is done as before, future hunting will be ensured. By performing rituals, hunters indicate their belonging to a privileged group of the local community. In the post-Soviet era, hunters in the Chukotkan villages regained the status of breadwinners, providing their settlements with basic protein needs. The traditional hunting of marine mammals has also provided these communities with cultural markers—traditional food, activities, knowledge, and customary laws—to preserve their identity. Ritual relationships, as part of customary law, continue to govern the life Native communities. Despite the dominant cash economy, the custom of sharing hunting products with other members of the community retains its basic features: donating meat to neighbors, sending hunting product to relatives, holding family holidays, and exchanging gifts with neighboring villages and reindeer herding camps.

Rituals also mark transitional states in the life of an individual and community. The first walrus or seal independently killed by a young man is accompanied by a ritual of initiation for the hunter. The initiation has a basic form that varies depending on the commitment of the family or elders to traditions. In the hunting teams, the elders simply make a symbolic punch on the new hunter's shoulder. The families observe a detailed ritual in which there is a dispute between the old man and the young man over the right to own the killed marine mammals, accompanied by a symbolic fight. The elder has always been the winner and becomes the owner of the animal. Then, the prey is butchered and handed out to neighbors. In some families, the face of the new hunter is painted with the blood of the first animal he gets. The face painting can be a complex system of lines or just a point anywhere on the face. The young man acquires the status of an adult member of the community and a breadwinner in the family.

Several holidays and rituals are not explicitly dedicated to walruses, but are indirectly related to these animals. After a long polar winter, food stocks in the community become scarce, and in the spring the first walrus hunt is a significant event. Hunters, launching boats into the sea, hold a ceremony. The first walrus taken is a great feast and occasion for the Thanksgiving ritual. The meat of the harvested walrus is shared among the whole village. In some cases, the captain of a walrus boat holds running, jumping, and wrestling competitions. The main prize is the tusks of the harvested walrus. Autumn walrus hunting provides meat and fat to the village for the long winter. Walrus coastal rookeries, where the animals haul out on land, are the most productive places for walrus hunting at this time. Before the beginning of the autumn season of walruses on coastal rookeries, the *owner* of the rookery performs a ritual dedicated to the master of the herd of walruses.

SUSTAINABILITY AND CHANGE IN RITUALS AND TRADITIONS

Rituals are sustainable because they are a vital foundation that strengthens traditional knowledge and customs. Together this system regulates the material, cognitive, and spiritual aspects of walrus hunting, and ultimately ensures the sustainable survival of the coastal community. However, the long-term acculturation of local communities is gradually changing the ritual practice of sea hunters over time. Ceremonies have been simplified because many features of ritual practices were not passed on to current generations of elders. The survival of rituals has been impacted by prohibitions, as ceremonies were either not performed or were not held publicly for decades. An example of the simplification of rituals is the comparison of the rites of initiation into hunters described earlier.

Rituals are not only simplified, but also forgotten. There are, for example, sacred places near settlements, the characteristic feature of which is a circle of walrus skulls. A visit to these places is taboo, but the reasons for the ban are now unknown. The parents of today's elders either performed the rituals secretly or did not perform them at all

Photo 18.4: Walrus hunting and children.

because of the authorities' persecution of traditional beliefs. Rituals also changed, not only because of prohibitions, but also under other influences. Technical innovations have increased the efficiency of walrus hunting and reduced the dependence of communities on natural circumstances, such as bad weather conditions, sea ice states, and short-time migration patterns of walruses. Hunters are able to travel long distances, and to find, harvest, and transport walruses to the village in a short time. In turn, this has contributed to a change in the worldviews of hunters. The facilitation of hunting through security improvements has changed the attitude of hunters towards the sea and walruses. This is a reasonable explanation why walruses, while remaining a key species of marine mammals for community hunting, do not have a holiday dedicated to them in modern Chukotkan culture.

Changes in the social organization of communities are also reflected in the ritual practice of walrus hunters. Today, hunters, providing about half the food of the villagers, are a small group in the village. According to official statistics, 36 hunting teams and 300 hunters deliver marine food to 14 Indigenous villages of Chukotka, supported by state subsidies. Even taking into account the fact that there are also villagers who hunt outside government subsidies, the proportion of sea hunters does not exceed 10 percent of the rural population. Accordingly, ritual hunting traditions are limited to a small number of participants.

A complex of beliefs and rituals is designed to help people cope with difficult periods in life. The question is whether this function of the ritual is applicable not in a specific situ-

Photo 18.5: Traditional walrus food.

ation for a small group of people, but during a period of social changes for Indigenous settlements. Modern Chukotkan communities have their own concerns and feelings, but they differ from those that were held before. The main cause of community concern in the past—the threat of hunger—is not relevant for villagers today. New generations of Chukotka villagers have a contradictory tendency to prefer the urban way of life, while worrying about maintaining their identity and traditional way of life.

Traditional subsistence ensured the survival of the Chukotka Native Peoples in the Arctic because it was based on a rational and harmonious interaction strategy between communities and wildlife. Careful observation of natural phenomena and animal behavior was part of a comprehensive system of traditional knowledge. In this frame of knowledge, the regulation of interactions with nature was carried out using experience, rituals, and restrictions. Compliance with traditions also provided a unique world view and culture for countless generations. However, in the history of Chukotka there were sociocultural shifts that made a gap between generations, breaking the chain of transfer of knowledge and traditions, and thereby bringing the unique culture and identity of Indigenous Peoples to the brink of extinction. Only the fact that the plans for Soviet reorganization left a place for traditional subsistence lessened the consequences of a widespread loss of identity among Indigenous Peoples, while ensuring their adaptation to the modern global world.

The traditional knowledge of the Chukotkan peoples about walruses is an important component in preserving the identity of the Chukchi and Siberian Yupik. Today, the older generation of Chukotka sea hunters follows the traditions of their ancestors in their interaction with walruses. At the heart of this relationship is respect for nature and marine mammals. Although the traditions and rituals have different explanations, they have a common goal: rational, effective, and safe harvest management. These rules are based on clear environmental principles and ensure the sustainability of traditional subsistence. For customary laws that have passed through a series of prohibitions and obstacles, their preservation and continued use is a testament to their strength and practical value. How these beliefs and the underlying attitudes will accommodate the new modes of hunting and living that come with modern technology and social influences is an open question.

WHITHER TRADITION AND RITUAL?

Whatever form they take among the younger generations in a time of rapid change, traditions and rituals that persist can provide a familiar landmark or a foundation for retaining some sense of stability in one's life and culture (Rytkheu 2011). A strong and respectful relationship to the local environment is also essential for understanding how to be safe when at sea and how to continue to provide food for one's family and community, in a sustainable way. Around the Arctic, local peoples have had to adjust and adapt to the arrival of newcomers. In the European Arctic, this has taken place over many centuries, whereas in the Asian and North American Arctic, the substantial presence of new arrivals is more recent. In all cases, change brings adjustment, but it need not bring the loss of entire cultures. The rich human past of the Arctic is also still part of the region's rich human present. And it can be part of the Arctic future, too, not as a relic of times gone by, but as a vital and vibrant part of the quest to live and thrive in a sustainable and meaningful way.

Traditional rituals and knowledge alone may not be enough to help Arctic communities through the changes that are coming, but without them, what do Arctic peoples have left of their past and of themselves? And how much have the rest of us lost, if we do not help sustain the living cultures of the Arctic?

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CHAPTER 19

RATE AND MAGNITUDE: THE HEART OF SCIENTIFIC CONCERN. A STORY ABOUT COPRODUCING KNOWLEDGE IN EAST GREENLAND

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COPRODUCTION OF KNOWLEDGE: AN INTRODUCTION

Twenty-five years after completing my PhD on the informal economy of seal hunting in East Greenland, I stumbled upon a diary from the start of my anthropological field work in the early 1990s. I was quickly deluged with the time-buried adventures, relationships, and impressions of the small East Greenlandic village of Isertoq, events and insights that could never have fit into my doctoral thesis (photo 19.1). During my fieldwork, I

Photo 19.1: Strategically located on a peninsula of the coastal zone we find the small East Greenlandic village of Isertoq.

printed and shipped out copies of the diaries and field notes to my father every week. I had learned from Earnest "Tiger" Burch, a fellow anthropologist working in Alaska with the Inupiat people in the 1950s, to always keep a spare copy of field notes somewhere else, and mine were sent by mail to Oslo. Burch himself learned the importance of this practice when his notebooks, kept in a small, wooden cabin, were one night engulfed in flames. Fleeing from the fire, Tiger remembered that six months of research—all his observations, conversations, and recordings—were inside the house, rapidly turning to ash. So, he did the most natural thing a scientist would think to do—he ran back inside after them. It took the help of Inupiat neighbors to carry him out of the smoke, but he saved the field notes.

My father, the faithful protector, reader and preserver of my field notes, saved mine. Upon reading them, I allowed the period of life in which I lived, comparatively isolated from the world, to resurface. I felt the objectivity—to which I was forced to bind my anthropological dissertation—slough off in layers, like the blubber of seal skin or calving glacial ice, and bloom again with visceral clarity and color. I was excited by the prospect of delving into the past, but there was also a poignancy to my time at the edge of world. A tenderness born of the connections formed and lost, strained and recovered, natural and frustrating, and all residing in fragile dualities somewhere deep inside my mind and heart.

My field research was a time rife with insight into human resilience, labored and alluring, with a piquancy that belied the harshness of Arctic life and the profundity of Indigenous knowledge and existence. It is the story I did not tell in the time leading up to my doctoral degree and in the years afterwards as I began my professional career as an anthropologist and climate scientist. Revisiting it now with the emotional padding of nearly a quarter of a century and a well-established scientific career, I realize that what is saved in these diaries and journals was never meant for the strict annals of anthropologic literature, nor was it meant to reinforce the established sensationalist approach to conveying Indigenous culture and their visible traditionality as seen by Western eyes. It is meant, really, to illuminate the landscapes inside each individual that are more complex than even the most extreme physical environments. And, in a world divided by all that is unique in these internal landscapes, it asks us if we might humble ourselves to different terrains of truth.

This humility requires us to be open and accepting of different kinds of knowledges—be they local, traditional, Indigenous or scientific. In 2020, we call this interaction and learning *coproduction of knowledge*. Coproduction of knowledge entails both collaboration within communities and between local communities, scientists and policy makers. By working together in deliberate ways, the local, regional, national, and international spheres can produce knowledge that creates comprehensive and inclu-

Photo 19.2: Boating and sledging for seal hunting.

sive understandings of complex issues, such as the combined effects of climatic and societal change.

It is impossible for me to think about Greenland without reflecting on the interactions between the Isertormeeq's traditional ecological knowledge and globalization. However, I also recognize the equally important collaboration between the Greenlandic context and my own knowledge as an anthropologist. All of these knowledges—the local community's, the scientist's, and the world's—interact in a complex meeting place of different practices that inevitably overlap, converge and diverge. Coproduction of knowledge provides us with an opportunity to gain a better understanding of how the Isertormeeq view their challenges and opportunities in the context of climatic and social change without losing the context of their cultural history. Succinctly, close cooperation between hunting households and researchers is essential, and our common inquiries are what will lead to salient adaptation solutions (photo 19.2).

THE PHYSICAL AND SOCIOCULTURAL COMPLEXITIES OF ARCTIC CHANGE

When I designed my research plan for my time in Isertoq in the early 1990s, I had a professional understanding of how such anthropological field studies were to be conducted but there was very little available information about what life would be like in the village where I intended to spend two years documenting and co-existing with a people whose culture the world assumed was in jeopardy. This global perception stems from that fact that, by the mid-1990s, seal skins were no longer a commodity to be bought and sold on the international market, a situation which would recur in the twenty-first century with a renewed EU Directive against the seal skin trade (photo 19.3). Thus, in the 1990s, Inuit people who lived off the land suffered.

Photo 19.3: Preparing the skin of a ringed seal *(Phoca hispida)*.

From the comfort of my home, I had wondered how international campaigns against sealing, such as that of Greenpeace in the 1980s and 1990s, affected people whose lives depended on these animals for food, culture, identity, and economy. This is what led me to Isertoq and East Greenland in the first place; here lived a people whose lives were centered around hunting marine mammals and fishing, a people whose lives were deeply connected to the ocean. They never walked far from the water's edge—unless polar bears had been sighted on the Greenland ice cap. It is the sea and the sea ice which holds their culture and skills.

Today, with the Arctic continuing to warm at more than twice the global mean, sea ice maximums have reached record lows, especially in the years between 2015 and 2018, posing unprecedented problems for peoples like the Isertormeeq. What was once multi-year, thick ice is now trending towards younger, thinner, seasonal ice coverage, which leads some climate models to suggest that the Arctic could be ice-free in the next few decades. Even with the adoption of stringent emission mitigation measures, the Greenland ice sheet, which continues to be one of the largest contributors to sea level rise, will continue to lose mass over the course of the century. Declining sea ice volumes have triggered shifts in marine algal blooms and the distribution of many Arctic species. These subsequent changes have the potential to harm the populations of mammals and fish upon which Indigenous Arctic communities depend.

When preparing for my field work nearly thirty-five years ago, sea ice was considered a relatively stable platform for hunting and travelling, and its presence was a given. I was interested in and concerned with the seasonal variation and type of ice that affected the availability of marine mammals and hunting and travelling conditions, but the thought that Greenlandic and other Arctic Indigenous Peoples would be faced with the disappearance of sea ice in the coming decades did not occur to me at the time. Environmental instability was never mentioned by the Isertormeeq either—their primary concerns were societal challenges and centralized policies. Having spent years in the northernmost polar reaches of Norway and Svalbard driving dog sleds and sewing expedition materials, the physical uncertainties of my project were less daunting than these societal aspects. On the multi-legged journey to reach Isertoq, it was also difficult not to be convinced of the indestructability of Greenland ice. Flying along the shoreline in a helicopter, a sense of adventure immediately set in and endured. Massive icebergs passed below us, floating within the deep and dramatic Sermilikfjord as we approached the Greenland icecap and the village, which comprised colorful houses perched across the rocky island.

As I adjusted to life in Isertoq, I observed and engaged Isertormeeq in conversations about adoption practices, hunting and fishing practices, and other tacit knowledge and social codes. I was fascinated and transfixed as I watched people go about their daily lives and I soon befriended an elderly Greenlandic woman, Bera, and her husband, Henning, from whom I learned the ins and outs of traditional Greenlandic seal skin preparation, hunting, fishing and ecology. We laughed a lot—particularly about my efforts to fit into Greenlandic life—which is an ice-breaking activity in any culture. The friendship with Bera and Henning marked my first introduction and acceptance into Isertoq, and my participation in the reciprocal and complex system of gift giving quickly integrated me into the daily flow of the Arctic community, even as that community continued to adapt to a changing world.

Bera began referring to me as her daughter and opened up about her life on the island with all of its social, cultural, and economic fluctuations over the course of her lifetime. It became clear that, as in all Arctic communities, participation in a globalized world brought new goods and technologies. I discovered that traditional sharing patterns here had found new routes once cash and store-bought goods were introduced, and I knew that these findings were corroborated by the experiences of other Arctic communities. Cash is a different currency than seal meat or fish, especially in Isertoq, where seal skins are stored in a dried condition, only to be completely prepared when cash is needed. This way, people avoid having to give away cash when asked. It is customary to share what you have in Isertoq, but cash does not easily fall in this category.

Participating in East Greenlandic culture was essential to comprehending people's perception of their own lives, livelihoods, and the natural environment. I focused on how seals integrated the economy and permeated all aspects of the culture from gender roles to sustenance, identity, and knowledge of the icescape. I learned quickly from hunting and gathering trips, afternoons spent preparing and cooking food and skins, visitations with children and women who performed bead work and other *piniartoq nulia* (hunter's wife) traditional hand crafts that there was a disparity not only between Isertoq's informal economy and the global economy, but also between the Isertormeeq's limited interaction with the outside world and their inevitable dependence on outside goods. They are thrust into globalization, whether they want to change or not. The rate and magnitude of change, both in climatic and societal conditions, are at the heart of a scientist's concern when learning from and studying Arctic communities.

THE IMPORTANCE OF THE LOCAL CONTEXT

In my first few weeks in Isertoq, and even within minutes of stepping off the helicopter, I was reminded that language defines the people who speak it (and that my rudimentary lessons in the East Greenlandic language would prove invaluable). In Isertoq and in East Greenland, words hold more than denominational meanings—they contain the history of the people who use them. I was told that, as an increasing number of traditional practices in East Greenland cease to exist, the words for those practices disappear as well. Thus, the history of the East Greenlandic culture changes as the verbalizations and their associated experiences are not passed on. The effect of this language loss is exacerbated by another fear: that the environmental and ecological knowledge that has sustained and protected Arctic communities for millennia will no longer hold true in the face of climate change.

Speaking with Bera and Henning's son, Viktor, I was exposed to this comprehensive understanding of environmental dynamics and am now able to better appreciate the importance of this knowledge amidst a rapidly changing Arctic climate and economy. Viktor talked excitedly about three polar pears he'd caught, and his practice of hunting every day. In early Summer, he explained, you'd never catch a polar bear; that season falls between February and April. At the end of May in 1994, the sea ice was beginning to melt, so dog sled hunting was on its way out for the time being and boat hunting would pick up relatively soon, especially if a strong storm, a *piteraq,* swept through the area, blowing the ice out to the North Atlantic. Of course, then hunters would have to contend with the fog that settles into the fjords in place of the ice and snow while they hunt for ringed and hooded seal, porpoise, cod, black guillemot, eider duck, ptarmigan, and other birds.

Later, in 2011, I learned from hunters and their families in West Greenland that the duration of sea-ice coverage had been reduced from six to two months a year, effectively halting travel on sea ice by dog sled. Hunting for ice-dependent species had more or less been replaced with fishing. Thus, Viktor's understanding of the calendar year and its relation to hunting practices have now been drastically changed by new realities. These changes—language loss, climate variation, and altered hunting practices—are all stressors to which it is necessary for Arctic Indigenous and non-Indigenous communities to adapt.

But, not only do these changing conditions threaten traditional ecological knowledge, they also pose risks to public health. Loss of ice and warmer seasons put Arctic communities at risk for storm exposure and coastal erosion. Isertoq is no stranger to intense storms, especially not with the looming katabatic winds sitting up at the top of the Greenlandic ice sheet; *piteraq*, as the locals called a particularly brutal type of storm, literally means "that which attacks you." These storms have wind speeds upwards of 80 meters per second and can take out a hunter, dogsled and all, with one gust. On top of *piteraqs*, the southeastern *neqqajaqs* bring precipitation and strong winds, wreaking havoc on food deliveries and travel.

I remember the first storm during my stay, which started with a particular type of rain, *sialic*. I went outside to assess the sky and immediately noticed the formation of lenticular clouds that signified the approach of a *piteraq*. There were other people outside their homes looking at the sky, but none of them moved to tie anything down. Shortly after, however, the wind began picking up trash and flinging it through the air. I looked through my window with amazement as the world outside became a blur of snow. The whole village seemed to blow away.

The storm howled through the night and died in the morning, though the northwest winds were still cuffing the island as day broke and my house continued to shake for hours. Holding onto my hat and glasses, I decided to explore the outdoors, where everything was covered in salt from the sea spray and the rocks were slick and dark with water and snow. When I made it to the water's edge, I stared, dumbstruck, at the view. The sea had blown open; the ice had been pushed out to the ocean leaving clear, white-capped water in its wake.

But even the resilience of hardy Isertoq is challenged by the storms that move towards the North Pole, bringing with them warmer air that exacerbates sea-ice melt and snow that insulates ice after a storm, restricting contact with freezing air. Climate change's oceanic warming also creates circumpolar health issues, including higher rates of exposure to marine contaminants, increased rates of vector-borne diseases, the appearance of new diseases associated with thawing permafrost, and compromised surface drinking water.

Adding to the trials of extreme weather, public safety, and increased ice melt is the continuing debate over how to incorporate Indigenous knowledge into adaptation efforts, despite demonstrated Indigenous interest in identifying, developing, and implementing adaptations that respond to climate change (photo 19.4). Approaches to mitigation and adaptation policy are stymied by the fact that every Arctic community will have its own set of stressors that require localized adaptation efforts and an appreciation of individual experiences. In fact, I found that the most natural and uncomplicated part of my East Greenlandic study was living with the storms and weather of the barren and exposed is-

Photo 19.4: Life comes back to normal after a snowstorm.

land while the most difficult task was understanding the internal worlds of those whom I lived with, interviewed, and encountered. Yet, the importance of understanding this local context for adaptation cannot be understated, especially as national decision makers are often considered *out of touch* with local conditions and challenges. To truly achieve a coproduction of knowledge, this local perspective is vital, especially in building lasting resilience for Arctic communities.

INDIGENOUS REALITIES: A CALL TO ACTION

Having traveled to a remote island to study an informal economic system that was largely controlled by these local conditions and challenges (e.g., the relationship between seal skins, successful hunting, gender roles, and cash), I knew I needed to experience the effort required to preserve the traditional Greenlandic way of life. Thus, I began helping Henning with his hunting preparations, especially since he had recently hurt his knee and fallen ill (Henning had a reputation for hardily traveling out into the hunting grounds even in poor weather conditions). Given the adoptive nature of my relationship with Henning and his wife, this activity felt natural and unthreatening to the family. Indeed, it was Bera who told me that I could accompany Henning on a hunting trip, something I'd longed to do since my arrival in the village.

Upon my return from that trip, however, Bera was uncharacteristically cold and silent. I sensed that, while I was out with Henning, other women must have come by and opened Bera's eyes to the cultural scandal of the outing, the subversion of gender roles it represented. In the subsequent days and weeks, Bera was terse with Henning and I was all but ignored by the once warm, motherly woman.

Though the despair of this social solecism seemed overwhelming, I worked steadfastly through the conflict by reaffirming my dedication to daily Greenlandic life, as well as my commitment to respecting the social structures of the community. I was humbled by the weight my actions carried in the small, insulated place, and I recognized how close I had come to losing my hard-won inclusion in Isertoq society. These systems and relationships were put in place by the community and the culture for a reason.

When I made my last departure from the village in July of 1995, I knew that I would never fully understand what made the Isortormeeq who they are. I was not brought up with their history, their language, their values, their way of being together; "To speak Greenlandic is not to think Greenlandic." No scientific study can ever truly recreate the past—only one's culture can do that. But the culture in question is changing quickly, and we must identify ways to integrate the knowledge that still exists into salient forms of climate adaptation.

After re-reading my field notes and diaries from the whirlwind that was 1994 to 1995, I realized that, while my time in Isertoq was short in the context of Indigenous history, these pages document a vital part of the village's adaptability. They simultaneously illustrate the massive challenges that Arctic communities face and chronicle the adaptive capacity and adaptation processes that are in place to respond. What's more, the resilience of the island community has less to do with the security of their physical environment and relies, instead, on their ability to make the most of the resources they have. Indeed, much traditional and time-tested knowledge in the Arctic was shaped and

Photo 19.5: Melting glacial ice and perspective of the village of Isertoq.

developed in the context of climatic variability, extremes, and change. Yet, today, we see unique obstacles in the form of outside stressors, historical legacies, policies, and rapid climate change that threaten to undermine this traditional resilience, making the coproduction of knowledge increasingly necessary.

Challenging our ability to understand the struggles of a given locality is the fact that we cannot conduct research everywhere. So, while context matters and is essential for including local perspectives, it still behooves us to develop knowledge that is generalizable and transferable; to create building blocks for collaboration without subscribing to purely broad-scale solutions to complex problems like climate change. This is even more critical for the Arctic, which, as we know, is where climate change is first felt.

Looking back on my time in East Greenland, I am grateful for the perspective given to me by the people I spent time with on Isertoq, many of whom are long gone from the earth (photo 19.5). That perspective reminds me how necessary the coproduction of knowledge is for community viability of Arctic Indigenous Peoples. Understanding the physical and cultural impacts on this rapidly changing region is of essence to developing relevant adaptation strategies and tools. Though the task of producing this knowledge in the modern world may seem daunting, I've seen first-hand that human beings have the faculties to work together, to save each other from despair and to celebrate and exalt in all life has to offer. In the midst of the climate crisis we now face as a global community, what is most important is that we accept that offer—and offer what we can in return.

CHAPTER 20

BOREAL FORCING OF THE NORTHWEST PASSAGE MARINE SYSTEM: A CORE RESILIENCE RESPONSE

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> "How is it possible for mankind to take advice when they will not so much as heed warnings?"
>
> JONATHAN SWIFT (1667-1745)

INTRODUCTION

This essay began as a dialog between an oceanographer (this author) and an ecologist (C.S. "Buzz" Holling) aboard an icebreaker in 2009, and continued with great enthusiasm into the mid-2010s. It is an unabashed plea for action, and I begin where the story started by going back and recalling the final paragraph in Holling (1973):

> A management approach based on resilience…would emphasize the need to keep options open, the need to view events in a regional rather than a local context, and the need to emphasize heterogeneity. Flowing from this would be not the presumption of sufficient knowledge, but the recognition of our ignorance; not the assumption that future events are expected, but that they will be unexpected. The resilience framework can accommodate this shift of perspective, for it does not require a precise capacity to predict the future, but only a qualitative capacity to devise systems that can absorb and accommodate future events in whatever unexpected form they may take.

To bring these words forward five decades and place them in the context of modern, existential change, I turn specifically to the coastal marine system (see table 20.1) of the Northwest Passage, Arctic Canada, a social-ecological continuum that connects the North Pacific, Arctic and North Atlantic oceans. Communities along this vast coastline, most of which are indigenous and rely to some degree on subsistence harvesting and fishing from the sea, exist within a complex adaptive system forced at several nested temporal and spatial scales. Such systems, currently under stress from climate change and other anthropological forcings, are subject to sudden flips into new functioning arrangements. I argue that focused monitoring is the only means to confirm change and detect surprise in this immense, non-linear and multi-scale system. The *central hypothesis* is that increased local understanding of impacts of global scale forcing on local conditions will transform a community's ability to self-govern their resources and operate as a conservation economy. The *core objective* is to suggest a sustained, community-linked marine observational network to measure the basic water properties that define

Table 20.1: The meaning of three essential terms in the title: Boreal forcing, marine system, and core resilience response

Boreal forcing	The external elements that drive the large-scale, poleward trajectory of climate and ecosystem change across existing biogeoclimatic gradients, stressing food webs and displacing resident species still farther north.
Marine system	All the interacting physical, geochemical, biological and human components—their heterogeneities, cycles, patterns and scales—that define and regulate structures and functions within a regime defined by its scale.
Core resilience response	An adaptive plan of action to detect and track critical elements of change within a social-ecological system as a necessary first step to the launch of those experiments required, at multiple scales, to maintain functions in a manner that aligns with local goals and values.

what animal can live where. This network of data collection then becomes the basis for two-way exchange of information and cross-scale analysis.

With important subsistence, cultural and spiritual elements to residents, the response of the animals of the ecosystems and their resilience to forced change and management practices hold special concern. Following an exhaustive, case study literature synthesis of Arctic social-ecological systems focused on Inuit regions, Falardeau and Bennett (2020) concluded that " . . . some social-ecological linkages are likely still overlooked or understudied, including the effects of changing marine ecosystems for cultural services that underpin people's adaptive capacity." I address here a small element of this gap and argue that better understanding of the ecological impacts that are likely to flow to sociocultural dimensions is critical to the fostering of adaptive capacity. At the same time, I acknowledge that ecological change is only half the story, and parallel work in understanding and monitoring sociocultural dimensions, and how they will be shaped by a changing marine system, will also be required." And while I use Arctic Canada as the focal scale, I posit that the general concept may be of widespread applicability to the millions of residents living elsewhere along Arctic seas and waterways.

To characterize the Northwest Passage, I will draw together elements of geological history, note special oceanographic qualities, identify pending threats and signs of ecological change, and recognize those who make it their home. I raise alarm at the damage that global change forcing could do to these social-ecological participants, and then propose a holistic, conceptual model for monitoring that may guide adaptation and management along new complex adaptive cycles that are inevitable. I base our future scenarios on projections of global-scale warming (IPCC 2018), sea-level rise (Horton et al. 2020), sea-ice retreat (SIMIP Community 2020) and key indicators of change both globally (Box et al. 2019) and within the Canadian Arctic marine system (Niemi et al. 2020).

Photo 20.1: Pangtirtung hamlet member Jason Etuangat and Fisheries and Ocean Canada technician Mike Dempsey participate in the Canadian Rangers Ocean Watch (CROW). This Inuit learning and development program is run by Pilimmaksaivik to sample water through the ice in Cambridge Bay, Nunavut. The CROW program was initiated by the author in 2009 as a partnership between the Canadian Department of National Defence and Fisheries and Ocean Canada.

With *adaptive* monitoring as our goal, I ask three simple questions: 1) what should be monitored across the full span of the Northwest Passage that is both achievable and fundamental to other monitoring programs at larger (global) and smaller (community) levels; 2) who should do the work; and 3) how can knowledge so-gained be shared and applied for the common good? The answer—for those who choose to read no farther—is 1) measure the physical and geochemical variables whose ranges set basic limits for marine life; 2) engage and empower the people who live there to measure these variables and record observable change in species; 3) use these shared data to follow an adaptive pathway to shared goals based on core values, support institutions and policies that sharpen the path, and discard institutions and policies that divert (Falardeau, Raudsepp-Hearne, and Bennett 2019).

THE NORTHWEST PASSAGE: A PLACE BOTH BIG AND SMALL

Owing to its immensity and the tangling of its complex networks, I begin with thought to scope and scale. As part of the global system the entire Arctic Ocean is small, only 3% of the global ocean's area, but through its impact on Earth's albedo and atmospheric and thermohaline circulations, the Arctic Ocean claims disproportionate influence on global climate. Canada's Arctic Seas, between the south tip of Hudson Bay (~ 51°N) and the northernmost extension of its Exclusive Economic Zone into the Arctic Ocean (~ 86°N), encompasses an area of over 4 million square kilometers, an area larger than that of

India. Its coastline bends around and through over 90 islands larger than 130 square kilometers, is over 160 thousand kilometers in length, and if straightened would wrap around the Earth over four times. The traditional Northwest Passage, between the western entrance at Amundsen Gulf and its eastern entrance at Lancaster Sound, is itself over 2,000 kilometers long. These scales illustrate the daunting task: the detection of change is challenged by its immense scale and made critical by its influence. Nevertheless, resilience planning does not back off from any challenge.

In building a comprehensive network for detection of change, and the source of change, it is critical to acknowledge that the waters of the Canadian Continental Shelf do not sit in isolation, but instead comprise a dynamic Arctic *outflow* shelf (Carmack and Wassmann 2006). Ocean source waters are collected from the east (Atlantic), west (Pacific) and north (Arctic), modified locally through local atmospheric and terrestrial river influences, and then delivered back into the North Atlantic. Importantly, each of these source waters bring their own, unique, physical and biogeochemical properties that constrain a through-flowing continuum of habitat and life. Any monitoring checklist must consider this fact if change is to be interpreted in the context of network connectivity.

URGENCY: LOOKING BACK AND THINKING FORWARD

Poetically and literally, every rock has a story, and global climate modelers are now exploring geological history as those stories of the past help to see the fast-moving future more sharply. New studies are revealing important facts. It is thought that multicellular life first developed in the early Proterozoic, over 500 million years ago, likely in shallow coastal waters where the ingredients of life are brought together (Fischer et al. 2018). Ironically, it is these same shallow waters that may now be most threatened by mass extinction. Indeed, it now appears, from combined geological and climate modelling studies that the Arctic Ocean lies at the center of action, as past extinctions appear to have begun in the high latitudes and moved equatorward (Penn et al. 2018). The projections of Earth temperatures for the next few decades can now be matched with climatic events covering the past 50 million years (Burke et al. 2018; Westerhold et al. 2020), findings that validate the current urgency of detection. I note that the rocks and substrate that comprise the Canadian Arctic span four billion years (Fensome et al. 2014), the full time of life on Earth, and draw confidence that growing attention to the geological record here and the waters that flow across them will inform as to where we are now and, with climate models applied, identify the threats posed by the encroaching Anthropocene. Thus prepared we can then explore, together, the uniqueness of current ecological systems operating in these waters and launch adaptive experiments for sustainability, all the while making ready for surprise.

While looking back in time gives clues to the possible and looking forward adds urgency for a resilience response, both provide a potential coping tool. Given that the signals of global heating are arriving first and fastest in the high latitude, with rapidly borealization of both marine (Polyakov et al. 2020) and terrestrial systems (Bhatt et al. 2014) one can, metaphorically, glimpse the future's early arrival. The observance of Arctic change impacts on life, and corresponding policy and management responses, can thus serve as lessons to other parts of the planet, where change is less rapid. We must appreciate the fact that by warming faster, the Arctic is giving humankind a looking glass of early warning, and perhaps a tool for coping with the greatest threat ever faced by our species.

THE EXISTENTIAL THREAT OF EXTIRPATION AND EXTINCTION

Observation- and model-based discussions of Arctic biological change have generally followed two lines of inquiry. The first, a bottom-up approach, involves the joint but counter-opposing roles of light and nutrient availability under conditions of sea-ice decline and altered salt-stratification. Often these works carry the presumption of homogeneity in the lateral, vertical and temporal distributions of photosynthesizing species, and relatively uniform conditions of nutrient availability, a supposition challenged by Brown and colleagues (Brown, Holding and Carmack 2020). The second, a more top-down view, involves the northward expansion of subarctic species, as ocean conditions

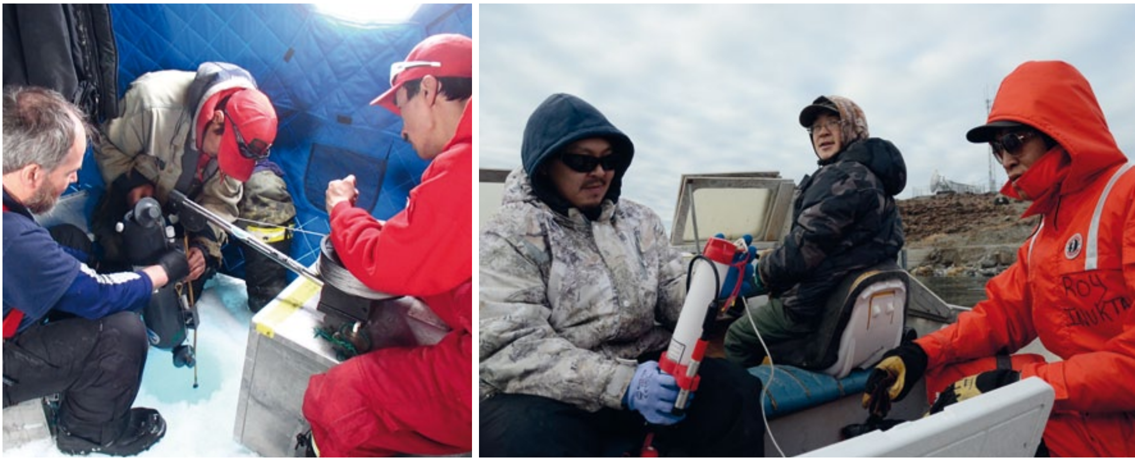

Photo 20.2: Hamlet members take part in monitoring and sampling projects. *Left*, Paulatuk hamlet members Johnny Ruben *(left)* and Ryan Green *(right)* participate with Fisheries and Oceans Canada technician Mike Dempsey in the Canadian Rangers Ocean Watch (CROW). The three are seen sampling water through the ice during mid-winter (-27°C) from a portable tent while crossing Darnley Bay, Northwest Territories, Canada, by snow machine. *Right*, Ulukhaktok hamlet members *(left to right)* Kelly Nigiyok, Kitok Pat Akhiatak, and Roy Inuktalik participate in the Ulukhaktok Aquatic Monitoring and Observation (ULU-AMO) program to deploy a CTD data logger (temperature, salinity, turbidity and oxygen with depth) at key coastal station locations to estimate the preferred habitat conditions of aquatic ectotherm species.

become more favorable to invading species, and less so for residents. Often these works carry the presumption that new species entering local food webs take on the ecological function of the species they replace, with minimal cascading effects, and that regionality plays no constraining role. I doubt this.

Our question, then, is how will extirpation (the disappearance of a species from a given area) and extinction (the complete disappearance of a species) play out in the Northwest Passage? It is fundamental that all organisms have evolved the physiological mechanisms they need to live where they do under the range of conditions they typically encounter. For example, all marine species have temperature, pH and oxygen limits within which to live (Pörtner and Farrell 2008). When these are exceeded too rapidly to allow adaptation, species either move or die. Rising water temperatures are already testing the physiological limits of ecologically and culturally invaluable species within the Northwest Passage, such as Arctic cod (Drost et al. 2016) and Arctic char (Gilbert and Thierney 2017). Loss of these critical species would reverberate through the entire food web (Steiner et al. 2019). However, extirpation will not occur uniformly or predictably but will spread along different pathways.

Given that all species have an environmental niche, let us ask, specifically, what key environmental parameters define limits for marine life in the Arctic marine system. Following Holling's anecdotal *rule of hand,* which states that any system, no matter how complex, will largely be constrained by a handful of key parameters, the trick is to find them and explore the interactions and feedback that give rise to regime shifts and emergent properties.[1] Applying Holling's rule of hand to extirpation, the list is surprisingly—and almost embarrassingly—short. Leading the way during global warming is, of course, temperature; all animals have specific thermal limits. When exceeded, either too hot or too cold, the animal is first stressed and then dies. And in between the too cold and too hot is *just right*, the thermal optimum, where species performance is maximized. Other parameters defining tolerance or energy flow include pH, dissolved oxygen, salinity, solar radiation, turbidity and nutrients; a short list of seven.

So, as a prelude to our conceptual model, picture now a one-dimensional plot of temperature on the horizontal axis, and with marks for the cold and hot limits between which a given animal must live. Next picture a two-dimensional plot with pH limits added in the vertical; now the animal is constrained to a more constrained *life space*. Adding a third dimension, say dissolved oxygen, restricts that life space even more, and so on into the multiple dimensions of habitat for that single species. When that animal is placed within the context of a food web, with who-eats-who connections, the outcome becomes even

[1] The *rule in hand* was passed along during numerous conversations with C.S. Holling, and appears in his memoirs (Holling 2017).

Photo 20.3: Cambridge Bay hamlet member Makaia Shannette Hikhaitok Havioyak assists her grandfather, Jerry Puglik, in collecting polar cod fry. The fish will be used in thermal limit experiments to quantify future species distribution and survival limits in this era of rapid climate change.

more uncertain, as differing species will occupy different limits and optima. Food web disruption will be un-uniform and likely non-linear. And, importantly, these same parameters are now being implicated in past global extinctions.

Given these threats, what do we do next? Fortunately, the right observers are already in place throughout the Northwest Passage, and the technical means to make these measurements are simple to use and cheap. All that remains is the empowerment of a network and infrastructure that supports training, logistics, and two-way exchange of data and knowledge.

TOWARDS A UNIFYING MONITORING NETWORK

Since the late 1980s the Intergovernmental Panel on Climate Change (IPCC) has taken the global lead in assessing and predicting the impacts of anthropogenic greenhouse gas emissions on global climate. But many—if not most—societal policy concerns are centered on climate change issues with *regional* (not global) spatial scales, *short* (not long) time scales and *heterogeneous* (not homogeneous) metrics of place and change. At these scales, the power of ecological sense-making, the process by which people give meaning to collective experience, becomes a critical ingredient (Whiteman and Cooper 2011).

In Arctic Canada, as elsewhere, deep understanding of the local, the immediate and the intimate lies with the people who remain connected to the land and marine environment for food, travel and survival; that is to say, the residents of coastal (aboriginal) communities (Carmack and Macdonald 2008; Huntington 2011). In recognition of this, extraordinary monitoring efforts—many of which are fully grounded in community participation—have already been launched, and new networks are growing, bringing together voices with different views and skills. It is fair to ask "what's new with this?" and the answer is "not much, really." Only that we start with the broad, existential threat of extirpation, relevant to all underlying scales and community well-being, and suggest a network purposely built to interpret and address emerging questions as they arise. I think such a network will not only provide the knowledge required for adaption should existing regimes 'flip' into new states, but also guide a shaping of responses to maintain core social values (cf. Falardeau, Raudsepp-Hearne, and Bennett 2019): which I refer to as a *core resilience response* (table 1).

EMPOWERING AN INCOMPLETE NETWORK

Monitoring is basically the ability to collect sets of relevant, intercomparable data over sustained periods of time to allow quantification of change within a system for decision-making purposes. That the ocean is a complex and interconnected system means that local change can have far-reaching effects across space and time scales, and vice versa. Applying the ideas of macroecology (Li 2002), this requires that we define a problem over a sufficiently large but achievable scale so that data sets can be compared over climate-scale gradients.

Many examples exist of excellent, community-based monitoring, but less effort has gone into linking communities across the *full* span of the Canadian Arctic marine domain; the nodes are there but not all the links. I think that the full value of traditional/local knowledge and community-based monitoring is best reached within a network, grounded on a simple, unifying conceptual model. Following this logical argument, the way forward seems clear: a community-based watch at the regional-scale carried out by community residents and drawing on Indigenous and local knowledge. Three guidelines are suggested: (1) that the suite of measurements must be fully comparable (e.g., simple measurements made with robust, off-the-shelf instruments); (2) that the data must flow two ways (e.g., from the communities to a central data center and then back again to the communities); and (3) that the project must live in full view on the world wide web. Support for the community-based study envisioned may best come from flexible intergovernmental agencies and creative NGOs where project adaptation and experimentation is more easily carried out. And if this can be done at the scale of the Northwest Passage, it could be scaled-up to the full pan-Arctic coastal system.

Conceptual models are powerful tools when applied to otherwise intractable problems. Ours is this. Simplistically, the Northwest Passage looks like this: a 2,000 km long *spongy tube* averaging 100 km in width, taking up water from two great subarctic oceans to its

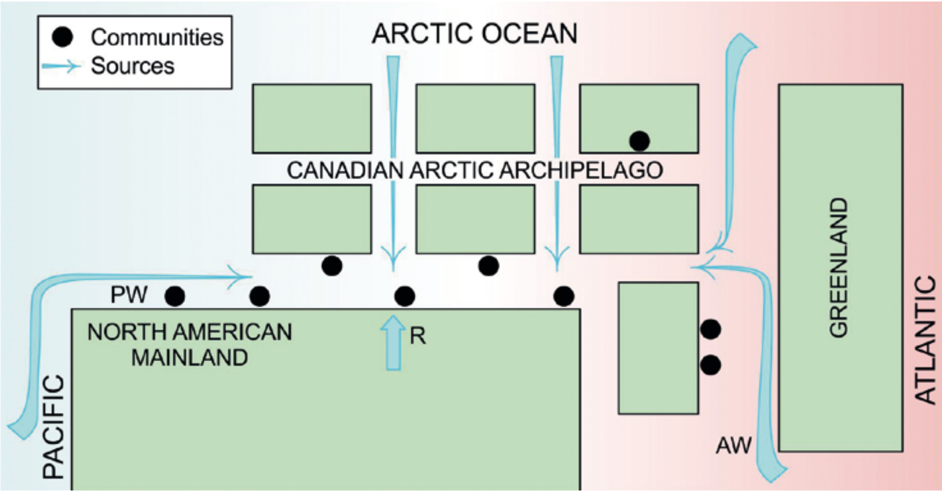

Figure 20.1: Schematic map of the Canadian Arctic Archipelago. The map shows boreal sources of water entering the Northwest Passage from the Pacific (PW) and Atlantic (AW) oceans, as well as outflows from the Arctic Ocean. R is run-off from hinterland, largely derived from moisture transport by westerly winds. Black dots schematically depict communities along the Northwest Passage.

east and west, drawing waters of Arctic origin from the North, receiving fresh waters from its diverse southern watersheds, and interacting with the atmosphere above (figure 20.1). The oft-cited adage of Indigenous Peoples that "everything is connected to everything" is here made manifest. Within this long narrow passage, environmental conditions and marine life are heterogeneous, almost beyond classification, and borealization, coming as it does from five directions, is non-linear and unpredictable. Yet people living along its shores have the potential to monitor, from boats, snow machines, and mobile labs, the life parameters noted above, and jointly—through knowledge exchange between communities—interpret the consequences. When mileposts are passed and tipping points approached, adaptive action can be taken to modify the system and avoid destructive flips, again with sense-making and community core values for guidance. I see this as eminently achievable.

FINALLY

When we think of global warming, we tend to think in terms of linear trends. But the physical and chemical processes that affect the climate system and life on Earth are extraordinarily complex and follow rate-governing equations that are fundamentally non-linear. The density of sea water, the capacity of the atmosphere to carry moisture, the rates of microbial utilization of oxygen and more are all governed by either exponential functions or power laws. And in an overly connected world growing more and more homogeneous and repeatedly exposed to shock, it is now, more than ever, imperative to close the gap

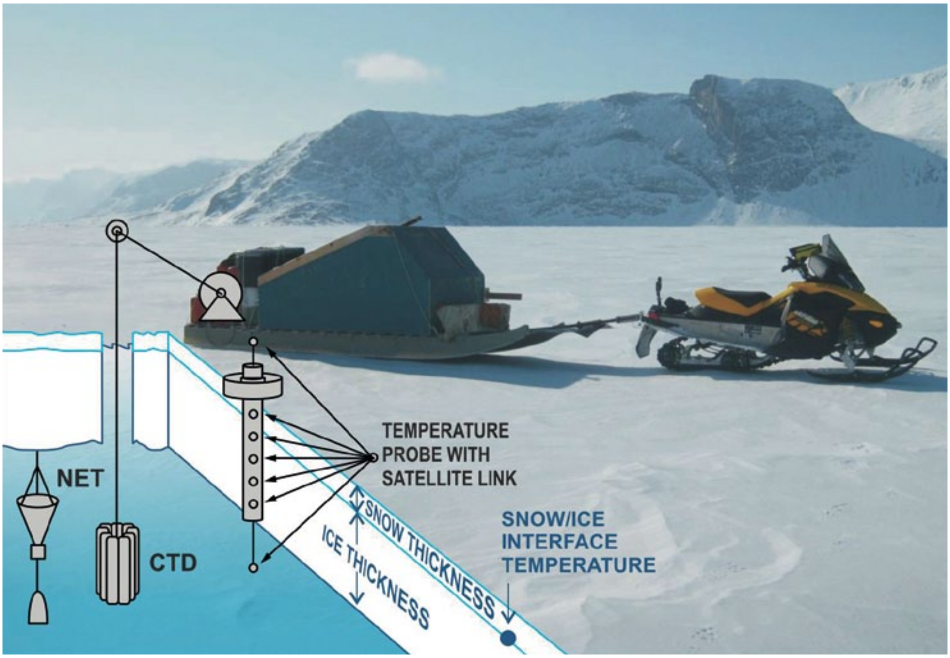

Figure 20.2: Cutaway graphic illustrating the snow mobiles for the deployment of oceanographic and sample collection through sea ice.

between science (e.g., discovery and evidence) and policy (e.g., preparedness and action). To assume linearity, or that nothing will change, and that public policy can carry on accordingly is to blindly accept social-ecological failure. The ideas expressed here are aimed at but a tiny bit of the problem—the marine system that surrounds northern North America—and how we might move towards a deeper understanding of its mechanics and values. Involvement of Indigenous communities bridges the present gap between the river, the sea, the region and the planet. We now have the planet's oceans being monitored; add to this the seas immediately offshore of the Indigenous communities and scales are bridged and people engaged.

Boreal forcing (table 1) will likely continue, displacing established species farther and farther north, across the continental shelves and slopes, and into the deep Arctic basins. But, for how long? Open a polar map, look down on the North Pole and you see the convergence of longitude lines, from 100 km at the equator to zero. Metaphorically, this constriction is like the box canyon in old American western movies, where cowboys drove wild horses and cattle into an ever-confined space. In this metaphor, Indigenous taxon, already disadvantaged by stresses on their thermal and other environmental limits, will have been driven farther and farther north by their boreal competitors (the cowboys) until the last cubic meter of their Arctic environment is gone. Will curious scientists then encircle that last cubic meter of true Arctic water, like archeologists, reconstructing what was there from the remnants? Perhaps they will find that remaining terrestrial and aquatic biota will have found refugia, to rebound under a future cooling event. Equally possible they will find themselves surrounded by trees, alligators and brightly colored fish. What will the fossil record say of us then?

And so, we are all on a journey of change, experiment and adaption; together we go through our liminal space, expecting surprise and knowing not the whither, but safer so prepared.

ACKNOWLEDGEMENTS

Much of this essay was inspired by conversations—beginning on an icebreaker transect of the Northwest Passage—with Crawford Stanley 'Buzz' Holling. His limitless imagination was able to immediately grasp the applications of Resilience thinking (panarchy, complex-adaptive systems, multi-stable states) to the social-ecological challenges of coastal communities through a structured network of local-scale observers exchanging data and knowledge across regional and global scales: he called this "a true panarchical experiment." My time with this man and his infectious enthusiasm and his undeterrable drive to understand complex systems was all too short. Nevertheless, those conversations led to notes, sketches and ideas that inspired the present essay. The extraordinary life and contributions of Buzz Holling are remembered by S. Carpenter and G. Peterson (2019). His memoirs (Holling 2017) are a joy to read and available online. He is missed by so many.

I wish to acknowledge Ilse Holling's support and approval of this essay. I also wish to thank P. Winsor for reminding me of the final paragraph of Holling (1973). Recent discussions with K. Brown and J. Holding on the regionality and seasonality of Arctic systems have been very useful. Finally, I am very grateful to P.F. Wassmann for allowing me to express these views.

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CHAPTER 21

WHY DID THE ARCTIC NOT COLLAPSE?

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"If at first, the idea is not absurd,
then there is no hope for it."

ALBERT EINSTEIN

May 4, 2049. My son turned 50 today, the age I was when this future was envisioned almost three decades earlier. Back then, global society had just left behind the second decade of the twenty-first century, a period, in a sense, of great revelations, destruction, and the onset of a renewal phase that would bring about today's Arctic. There were many reasons why people thought today's future may never become reality: governments around the world were becoming increasingly protectionist; global transit was a swift vector to spread disease the world was unprepared for, creating additional unwarranted xenophobia; species and habitat loss was at an all-time high; and the realization that we had created the Anthropocene was emergent in the public consciousness. While the media was caught in 24-hour news cycles, missing the issues that mattered to our future survival and well-being, we were nowhere close on track to meeting the Paris 1.5°C target by 2100. The latest report by the Intergovernmental Panel on Climate Change (IPCC) on oceans and cryosphere pointed toward faster and more severe impacts than previously estimated (IPCC 2019).

Reflecting on this today, it seems like a miracle that the proliferation of fungal and dinoflagellate parasites did not collapse global phytoplankton stocks. It seems like a miracle that marine food webs were not completely restructured, threatening global food security and economic and social stability. It seems like a miracle that we are not, as I write this, without a Greenland ice sheet; without summer sea ice; without narwhal, polar bear, and walrus; without permafrost and concomitant catastrophic Arctic infrastructure loss, and without having lost Arctic Peoples way of life, language, and culture.

Note: The views and opinions expressed in this essay are those of the author and do not necessarily reflect the official policy or position of his employer or any other agency or organization.

BEHAVIORAL REVOLUTION

Although hard to believe in such a future at the time, this miracle was human made! As the old proverb goes, "necessity is the mother of invention". Dealing with a global pandemic and the climate crisis with its increasingly global impacts, was an existential necessity. It catalyzed a range of new discoveries, structures, and behaviors, including astounding technological innovations and unparalleled levels of global cooperation.

Back in 2018, I had rediscovered C.S. Holling's 1973 publication on Resilience and Stability of Ecological Systems. The fact that he had laid the foundation for all this work almost fifty years earlier made me think of temporal scales of change—in nature, in society, in science—and so I found myself browsing through Gunderson and Holling's book *Panarchy* (2001). In Chapter 1, there is a section titled "Why Has the World Not Collapsed?", which they answer with two reasons: 1) the astounding resiliency of natural ecological systems whereby functional integrity is maintained despite experiencing wide changes, and 2) human behavior and creative adaptability when necessity calls. For systems that experience rapid changes, where stability systems are shifting at multiple scales and with discontinuous structure, the authors describe a world view of *nature evolving*. What had been missing up to this point was the human counterpart to this: an evolved behavior and evolving management and policy framework, actively adaptive to its fullest sense. A sys-

Photo 21.1: Arctic sea ice and snow drifts in Bering Strait, March 2009.

Photo 21.2: Sea-ice research station in the northern Bering Sea, March 2009.

tem wherein people and institutions are willing to be flexible and actively learn, working and adapting across scales and geopolitical boundaries, matching the scale of ecological change and the adaptive capacity of its components, taking into account the inherent non-linearity of natural systems at multiple scales.

As always, it was the right confluence of a multitude of thoughts, events and actions at the right time that ultimately created the necessary step change, a behavioral revolution. This revolution may perhaps reach the historical significance of past big transformative events like the agricultural, industrial and technological revolutions. Time will tell. If I had to pick a time when the transformation started, I would highlight late 2020, early 2021. Humanity was finally getting a handle on the Covid-19 pandemic. We did so with great losses, and revealing systemic global inadequacies in our social, economic and political frameworks and institutions to deal with events of this scale. What could, in retrospect, be considered a modern global social experiment, bringing life as we knew it almost to a halt around the world, led to a critical mass in our collective consciousness to support global change. We realized that the majority of governments were not going to get past their own interests and embrace global socio-ecological health and resiliency as their core value, working across borders for the greater good. We realized that inaction was a choice, a detrimental one; that all people of the world have much more in common than not; and that ruling by fear had to come to an end.

Recognizing the similarities between that global health crises and the intensifying global climate crisis, individuals, cities, tribes, and businesses acted. Driven by social, economic, and environmental interests on multi-decadal scales beyond election cycles, a sustainable, resilient, and globally integrated socio-economic-ecological agenda was pushed forward. Ultimately, it is what most people wanted, what most people realized we needed. People, not governments, started controlling the narrative, making their voices heard at all levels and sectors; governments world-wide eventually conceded, international organizations supported. And so, we turned our creativity and instinct for survival away from the individual person, country or business, toward the common, fundamentally transforming global behavior.

Human psychology and policy analysts had predicted the need for such a trigger event to achieve global change. In an essay published by Langan-Riekhof, Avanni, and Janetti (2017) from the Brookings Institute, the authors pointed out that once a crisis is defined, the problem can be reframed. Asking the fundamental underlying questions otherwise ignored or taken for granted, can lead to innovative solutions and global cooperation not seen before:

> The key to begin to address this massive [climate] crisis and promote a virtuous cycle of behaviors requires leaders across the globe . . . to recognize, define, and take ownership of the problem. As the signs of climate change have increased in the past few years, international cooperation to slow the progression and manage the effects already have increased—albeit slowly. . . . To get widespread support for difficult policy changes in energy production, agriculture, and consumption, leaders in the public and private sectors have a responsibility to reframe this crisis as everyone's problem and then develop partnerships to find innovative ways to limit and hopefully, reverse the impact.

Nowhere was the transformation more effective than in the Arctic. For decades, people and institutions like the Inuit Circumpolar Council, the Arctic Council, the International Arctic Science Committee, the Arctic Economic Council, and the Study for Environmental Arctic Change, had endeavored, each in their own way, to create One Arctic. The vision of a common Arctic, linked by common beauty, heritage, knowledge, interest, and need, would become reality. Past agreements and accomplishments in the Arctic were fertile ground for this new global, collaborative thinking.

GLOBAL RESPONSE

Within a couple of years into the behavioral revolution, Arctic biodiversity targets were integrated into national biodiversity strategies and action plans. The Central Arctic Ocean Fisheries Agreement signed in 2018 was expanded into The Arctic Treaty, paralleling the Antarctic World Park and Antarctic Treaty framework. Wildlife, ecosystems, minerals and oil resources were to be protected from harm and exploitation for the next fifty years.

Photo 21.3: Spectacled eiders (*Somateria fischeri*) in a lead south of St. Lawrence Island, Bering Sea, March 2009.

Global subsidies of hydrocarbons (totaling over USD 5 trillion per year, over 6% of global GDP back in 2017), were halted. This led to a direct reduction in global carbon emissions of roughly 30 percent, to a reduction in air pollution deaths of over 40 percent, and increased governments' revenue by over 3.5% of GDP (Coady et al. 2019). Fossil fuel companies had seen this coming and, indeed, many of them had already started re-inventing themselves as energy companies. Private industry, ready for this transition and recognizing their key role in creating energy solutions, together with governments backed by these new resources, and both pushed by public demand, created new public-private partnerships to implement a new renewable energy-mix solutions across the globe (IEA 2020). Ocean-based activities such as ocean-based renewable energy, restoration of coastal and marine ecosystems, changes in fisheries, aquaculture, and maritime transport, dietary shifts, and seabed carbon storage, were comprehensively implemented. This eliminated an additional 12 Gt of CO_2 emissions per year, contributing over 20% towards the greenhouse gas emissions reduction target set for 2050 at the time (Hoegh-Guldberg et al. 2019). In the Arctic, and many other rural areas around the world, this energy transition further took the form of efficient micro-grids, fueled by innovative new batteries and other technologies, fundamentally altering the standard of living for Arctic residents.

Indirectly, this energy transition cascaded benefits to many other facets of society, including increased support for micro-economies in developing regions. For example, in an effort to severely reduce energy consumption, data centers and super-computer fa-

Photo 21.4: Mackenzie River Delta near Inuvik, NWT, Canada, October 2016.

cilities requiring lots of equipment cooling, moved into the Arctic. This was in part possible because by then, the Arctic, like the rest of world, had much improved communication thanks to new comprehensive low earth orbit satellite constellations. This not only decreased emissions, but also supported local capacity building and provided a multitude of jobs for Arctic residents. In addition, an innovative circular economy model (from production of raw materials to reclamation and reintegration of spent materials into new products) reduced plastic pollution and fueled local economies (Balton et al. 2020). Fostering blue economy principles and sustainable development goals became a priority. The initial advice in the 2020 report of the High Level Panel for a Sustainable Ocean Economy positioned the ocean as an agent for earth-system resilience and human well-being, and as a political arena for united global action.[1]

Little by little, the energy transition increased overall sustainable living. It transformed buildings and urban spaces, reduced air, soil, land and water pollution and, most importantly, led to an ever-increasing awareness of our global connectivity, communality, and interdependency. This awareness continues to reinforce the behavioral revolution at all levels to this day. Wealthy individuals, organizations and countries, for example, recognizing that their own prosperity depends on a stable global society, have been actively doing their part to enhance efforts to safeguard essential human needs, like global food security and health. They support education and regional and institutional capacity building.

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[1] The High Level Panel for a Sustainable Ocean Economy is a unique group of world leaders and experts committed to developing, catalyzing and supporting solutions for ocean health and wealth in policy, governance, technology and finance. See www.oceanpanel.org for more details.

ECOSYSTEM TRANSFORMATION

This transformation, of course, took time. Upcoming atmospheric conditions that were already unavoidable due to GHG emissions in the past decades continued to modify environmental and social-economic conditions. The Arctic continued to warm and Arctic sea ice to decrease during the 2020s and '30s. The Arctic Ocean soundscape was radically modified by many-fold increases in commercial trans-Arctic shipping activities, affecting the distribution, abundance and availability of fishes and marine mammals (although I am happy to report that the new collaborations between naval architects, commercial ship operators, software engineers, and marine ecologists started in the 2030s has created acoustic solutions that transformed the industry and are already mitigating this problem in the world's oceans).

The Arctic marine and terrestrial ecosystem transformed into a system we would not previously have characterized as being Arctic; with abundant salmon, pollock, flounder and sand lance, puffins and shearwaters, humpback and killer whales, white-tailed deer, coyotes, starlings, and deciduous trees. Coastal erosion transformed coastal habitats, and cultural sites were lost to the sea. Arctic and global weather patterns became more variable and increasingly unpredictable. Storm intensity and frequency continued to increase and combined with sea-level rise, created havoc to coastal communities, critical infrastructure, and agriculture. The traditional way of life of Arctic Peoples was severely impacted. For almost two more decades humanity struggled to adapt before the effects of the behavioral revolution and concomitant new actions helped turn the corner in

Photo 21.5: Pancake sea ice in the Bering Sea, March 2009.

global greenhouse gas concentrations. Slowly, the system started to re-organize into a renewed manageable stability.

SOCIETAL TRANSFORMATION

As I gaze out over the Arctic Ocean, now in my eighties, I would be remiss not to mention a few other societal changes that occurred since the 2020s that have helped sustain the behavioral transformation. From an information, communication and media perspective, commercially driven content was largely disincentivized by doing away with the gross ratings point system[2] and click-through[3] and cost-per-view rates.[4] The public demanded that scientific and socio-economic information be communicated directly and clearly from its sources, not filtered through media channels that could misinterpret, chose to misrepresent or sensationalize it to improve ratings or promote a biased agenda. This approach finally cut through the surreal situation of fake news, alternative facts, and crazy 24-hour media cycle frenzy we were stuck in. The result has been refreshingly unbiased communication about issues that actually matter to societal well-being.

Science and science-management underwent their own transformation. Academic institutions around the world started rewarding their faculty for engaging with the public, communicating scientific knowledge and findings in a generally accessible manner, and focusing on problems that directly contribute to the achievement of specific, desired societal outcomes. This institutional change fostered and prioritized much needed use-inspired research, and created a new social contract, whereby scientists and their institutions became fully engaged with all aspects of society in co-creating scalable solutions to heal people and the environment. Science-funding organizations followed suit. Much needed fundamental research initiatives continued, but use-inspired, co-developed, and co-produced research is now increasingly supported. In the Arctic in particular, funding organizations have since been encouraging, sometimes even requiring, the bridging and integration of scientific and local and traditional knowledge, policy perspectives, and business opportunities.

Finally, from a natural resource management and related policies perspective, we moved to resilience-based governance within a social-ecological systems framework (Garmestani and Benson 2013). This now includes explicit organizational learning, cross-scale linkages, and an adaptive capacity to govern in a more flexible, iterative, and adaptive

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[2] A standard measure in advertising that measures advertising impact based on a percent of the target market reached multiplied by the exposure frequency.

[3] The ratio of users who click on a specific link to the number of total users who view a page, e-mail, or advertisement. It is commonly used to measure the success of an online advertising campaign for a particular website as well as the effectiveness of e-mail campaigns.

[4] The price an advertiser pays for every instance that their video ad gets played.

Photo 21.6: Approaching the US Coast Guard cutter *Healy* near St. Lawrence Island, Bering Sea, March 2009.

manner, avoiding the previously prevalent policy-science process disconnect (Rice 2011). In the Arctic, increased institutional capacity has enabled fully supported, internationally coordinated, cross-scalar, community-based, monitoring programs of the terrestrial and marine ecosystems. Tiered thresholds[5] linked to management actions have been adopted, set by people who live in the Arctic, and coordinated with national and international resource management bodies. It seems to be working thus far, with sustainable populations of fish, birds and mammals, and traditional use practices.

RESILIENT FUTURE

We have come a long way since 2020, but the work is of course not done. The World Economic Forum still lists environmental threats and impacts in their top five global concerns. It has been encouraging, however, that they have increasingly added a "most effective and beneficial actions" category to help continue or strengthen this transformation towards global sustainability and resiliency thinking. Issues related to over-population (e.g., food security, resource distribution, habitat protection, health) and maintaining social justice, continue to be challenges. We need to keep a close watch on these chal-

[5] A phased, stepwise approach to thresholds, whereby different management actions are tied to different degrees of impacts measured by reaching different levels of thresholds, rather than just assigning a singular, poorly understood, and usually more catastrophic threshold or tipping point until taking action. Tiered thresholds are an important component of adaptive management, providing consistency and flexibility.

lenges in this integrated global management model. If history, human psychology, and ecology have taught us anything, it is that the current state is fragile, that natural and anthropogenic perturbations will act additively at scales we wish to ignore, and that our systems and institutions are not as resilient to fear and greed as we would like to think they are. We must continue to support and verify the effectiveness of the transformative measures implemented in the last three decades. We must remain open-minded, tolerant, flexible, adaptive, and continuously hold our institutions and leaders accountable.

We have made it this far and the Arctic has not collapsed despite our hubris. I shudder to think what world our children would have inherited had we failed to transform our behavior.

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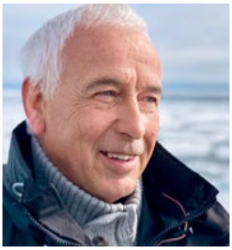

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Climate change in the Arctic Ocean has stirred a remarkable surge of interest and concern. Study after study has revealed the astonishing speed of physical, chemical, ecological, and economic change throughout the expanse of the Arctic. What is more, the consequences of the changing Arctic are not restricted to the Arctic itself, but affect everyone in the Northern Hemisphere, ranging as they do from extreme weather to resource availability and food security, with implications for politics, economics, and sociology. The challenge is to comprehend the full extent and variety of these consequences, and meeting this challenge will demand a multi- and transdisciplinary understanding. Only by this means can we hope to map out a knowledge-based ecosystem and move toward knowledge-based resource management—the essential precondition for any sustainable future.

In this book, leading international experts, from many fields of science and across the entire pan-Arctic region, give their specific takes on where the Arctic Ocean is heading. All have taken care in their writing not to exclude non-experts, in the conviction that multi- and transdisciplinarity can only be achieved when communication and outreach are not tribal in nature. The recurrent guiding theme throughout these pages is "Whither the Arctic Ocean?" Taken in concert, the essays synthesize the current state of scientific knowledge to project how climate change may impact on the Arctic Ocean and the continents around it. How can and how should we prepare for the imminent future that is already lapping at the threshold of the commons? What readers will hopefully take from this multi- and transdisciplinary endeavor is not the individual perspective of each contribution, but the picture that emerges across the entire suite of essays. As we move into a near future that will encompass both the probable and surprises, this book attempts to conjure the multi-dimensional space in which a sustainable future must be brought into being.

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