Chapter 7
The ARCPATH Project: Assessing Risky Environments and Rapid Change: Research on Climate, Adaptation and Coastal Communities in the North Atlantic Arctic

Astrid E. J. Ogilvie, Yongqi Gao, Níels Einarsson, Noel Keenlyside, and Leslie A. King

Abstract The NordForsk Centre of Excellence-funded project *Arctic Climate Predictions: Pathways to Resilient, Sustainable Societies* has as its acronym "ARCPATH" which reflects its focus on the Arctic region and the NordForsk focus on "pathways to sustainability". ARCPATH is a ground-breaking project designed specifically to synthesize results derived from a variety of traditionally very different and separate academic disciplines. In this spirit, the project seeks to address the complex and interlinked issues of climate and socio-economic change occurring in the Arctic by focusing on near-term changes, with the overarching goal of fostering responsible and sustainable development. This requires the reconciliation of environmental, social, and economic demands. These aspects are central to the project's three main goals: *(1) To predict regional changes in Arctic climate over the coming decades using innovative methods to capture both anthropogenic and natural factors in global and high-resolution regional models; (2) To increase understanding and reduce uncertainties regarding how changes in climate interact with multiple societal factors, including the development of local and regional adaptation mea-*

A. E. J. Ogilvie (✉) · N. Einarsson
Stefansson Arctic Centre, Akureyri, Iceland
e-mail: astrid.ogilvie@svs.is; ne@unak.is

Y. Gao
Nansen Environmental and Remote Sensing Centre, Bergen, Norway
e-mail: yonqi.gao@nersc.no

N. Keenlyside
University of Bergen, Bergen, Norway
e-mail: noel.keenlyside@gfi.uib.no

L. A. King
Royal Roads University, Victoria, Canada
e-mail: leslie.king@royal.roads.ca

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sures; (3) To combine improved regional climate predictions with enhanced understanding of environmental, societal, and economic interactions in order to supply new knowledge on potential "pathways to action".

Keywords Adaptation · ARCPATH · Climate change · Coastal communities · Sustainability

7.1 Introduction

The NordForsk Centre of Excellence-funded project *Arctic Climate Predictions: Pathways to Resilient, Sustainable Societies* has as its acronym "ARCPATH" which reflects its focus on the Arctic region and the NordForsk focus on "pathways to sustainability". The project's home and leadership are shared by the Nansen Environmental and Remote Sensing Centre (NERSC) in Bergen, Norway (Dr Yongqi Gao as lead) and the Stefansson Arctic Institute in Akureyri, Iceland (Dr Astrid Ogilvie as co-lead). The project websites are: http://www.ncoe-arcpath.org/ and http://www.svs.is/en/projects/arcpath. ARCPATH is a ground-breaking project designed specifically to synthesize results derived from a variety of traditionally very different and separate academic disciplines. In this spirit, the project seeks to address the complex and interlinked issues of climate and socio-economic change occurring in the Arctic by focusing on near-term changes, with the overarching goal of fostering responsible and sustainable development. This requires the reconciliation of environmental, social, and economic demands. These aspects are central to the project's three main goals: *(1) To predict regional changes in Arctic climate over the coming decades using innovative methods to capture both anthropogenic and natural factors in global and high-resolution regional models; (2) To increase understanding and reduce uncertainties regarding how changes in climate interact with multiple societal factors, including the development of local and regional adaptation measures; (3) To combine improved regional climate predictions with enhanced understanding of environmental, societal, and economic interactions in order to supply new knowledge on potential "pathways to action".*

ARCPATH methods involve extensive cross-disciplinary collaboration including contributions from: climatology (global modelling; dynamic downscaling; historical climatology); environmental science; economics; oceanography and cryosphere research; marine and fisheries biology; fisheries management; anthropology; governance systems; human eco-dynamics; and traditional ecological and local knowledge. Drawing on these separate but interlinking disciplines is enabling ARCPATH to form a truly synergistic Centre of Excellence. The project is collecting, assembling, and analysing a wide variety of different data sets and information with a focus on local communities in Iceland, Greenland and northern Norway. ARCPATH methods include the use of: (1) Earth System Models – the Norwegian Climate Prediction Model (NorCPM) and the European ESM (EC-Earth) Model with

assimilation of data from oceans and sea ice in order to perform global climate predictions; (2) Regional Arctic Climate Models to perform Arctic climate predictions; (3) Quantitative economic modelling, supported by qualitative interviews. The quantitative modelling follows the Economics of Ecosystems and Biodiversity (http://www.teebweb.org/) ecosystem services economic modelling framework. ARCPATH uses proven ethnographic research methods to solicit community insights concerning local changes, and to document how people are adapting/adjusting to these changes and impacts. The main social science research methods involve: participant observation, semi-structured and specialist interviews, official documents and surveys (see e.g., Fowler and Mangione 1990; Cochrane et al. 2008; Malinauskaite et al. 2019a). See also the chapter by Chambers and colleagues in this volume on community engagement. Evaluation of historical data follows established methods of analysis (Ogilvie 2010).

7.2 ARCPATH's Work Packages

The ARCPATH project is structured in such a way that there are seven discrete but interlinked work packages. The main goal of Work Package 1, *Arctic Linkages: Climate, Environmental Change, and Human Eco-Dynamics,* is to form an historical context for the project as a whole in that it is exploring and establishing linkages among changes in climate, social-ecological systems, and marine systems. The main objective of Work Package 2, *Improved Global Climate Prediction by Initialization of Arctic Sea Ice and Sea-Surface Temperatures,* is to improve our capability for decadal climate predictions by starting the predictions from realistic ocean and sea-ice conditions. The climate modelling and prediction aspects are described in more detail in the chapter in this volume by Shuting Yang and other ARCPATH colleagues. The main goal of Work Package 3, *Arctic Climate Predictions and Regional Downscaling,* is to improve climate predictions for the Arctic/Nordic Seas to the year 2030 by using high-resolution global-coupled simulations and regional downscalings. The main focus of Work Package 4, *Climate, Social-Ecological Systems, Cetaceans and Tourism* is to analyse to what extent climate change, tourism, and industrial development puts cetaceans (and human societies dependent on their use) under increasing and unsustainable pressure. Thus there is an integrative focus on marine changes in the Arctic, with particular regard to linkages among environmental changes and changes in cetacean populations, and the growth of whale-watching tourism. The emphasis in Work Package 5 is on *Marine Governance, Security and Rapid Social and Environmental Change* has considerable overlap with Work Package 4. Recent work has concentrated on field research on fisheries governance issues, including investigating social and economic impacts of Individual Transferable Quota (ITQ) systems in coastal communities. ARCPATH places much emphasis on interdisciplinary synthesis and Work Package 6, *Synthesis*, focuses entirely on efforts at synthesis among the individual work packages of the project. As this is the topic of Chap. 18 of this volume, its undertakings will not

discussed here except to note that this work package is designed to: (1) Harvest the principal scientific findings of ARCPATH and to generate new cross-cutting insights and concepts; (2) Explore the policy and action relevance of these findings; (3) Mobilize the generated knowledge in order share it with the academic community, policy-makers, practitioners, NGOs, the media and the general public; and (4) Identify gaps in knowledge and directions for future research. Furthermore, although researchers are now recognizing the importance of synthesis of research findings in order to facilitate knowledge mobilization and project legacy, many of these projects attempt to conduct synthesis at the very end of the research. ARCPATH is unique in that it is developing methods of building synthesis into the research process at all phases of research from design to application and legacy. Finally, Work Package 7 encompasses *Project Management and Dissemination*. The project is managed by the project leaders, Yongqi Gao and Astrid Ogilvie, with assistance from Project Manager, Kjetil Lygre. In addition to this, ARCPATH has an executive committee drawn from the work package leaders and an advisory board drawn from colleagues who are leaders in their fields and who have extensive experience in the fields of ARCPATH research. The following section describes the context for ARCPATH research efforts.

7.3 Arctic and Subarctic Change

Evidence of striking changes in global and Arctic climate over recent decades has increased dramatically and a large body of literature has ensued. The *Arctic Human Development Report* (AHDR, Einarsson et al. 2004) and the *Arctic Climate Impacts Assessment* (ACIA 2005) are examples of major studies that have focused on the rapid warming of the Arctic and its potential impacts on both Arctic and global communities. Their findings, even more compelling now than a decade ago, continue to be corroborated by other inquiries (Forbes 2011; IPCC 2014; IPCC SR 15 2018; AHDR 2014; Stroeve et al. 2014; Kahn 2016; Overland et al. 2018a, b; Arctic Report Card 2019; Box et al. 2019; Bravo 2019).

Rapid changes in the Arctic and globally may also include regime shifts that interact with one another to cause cascading effects (Rocha et al. 2018). The IPCC Fifth Assessment report (2014) concluded: “Effective decision-making to limit climate change and its effects can be informed by a wide range of analytical approaches for evaluating expected risks and benefits, recognizing the importance of governance, ethical dimensions, equity, value judgments, economic assessments and diverse perceptions and responses to risk and uncertainty” (*Summary for Policymakers*, 3.1.)

Focusing on specific locations for in-depth studies, ARCPATH considers these broad environmental and societal concerns in the context of developments also in the wider Arctic and Subarctic. Today, much research is being conducted in Alaska and on the north coast of British Columbia regarding the impacts of rapid environmental and socio-economic changes, marine mammal health and human-whale

interactions and conflicts (Moore 2014; Neilson et al. 2012; Fraker 2013). In Alaska, whales and whaling communities are impacted significantly by climate change and biodiversity loss (Kishigami 2010). In particular, whaling communities are seeking new livelihood strategies and opportunities for economic development while trying to maintain their cultural connection to whales and whaling (Druckenmiller et al. 2012). ARCPATH draws on this research and identifies implications for the wider Arctic and Subarctic world.

7.4 Global and Local Climate Change in the Arctic

Figure 7.1, below, shows the annual-mean temperature variations over the North Atlantic Arctic compared with global-mean variations. Although far from synchronous there are noticeable similarities between the two. Particularly striking is the early-twentieth-century global warming from 1920–1940. This warming has been attributed to a combination of anthropogenic (aerosols and greenhouse gas) factors as well as natural fluctuations within the climate system associated with the Pacific and Atlantic Oceans (Tokinaga et al. 2017). In particular the warming of the tropical Pacific and cooling of the northwestern Pacific during this period forced atmospheric circulation changes that warmed the Arctic (Svendsen et al. 2018).

The natural forcing related to Atlantic Multidecadal variability, also commonly known as the Atlantic Multidecadal Oscillation (AMO), is reflected strongly in the North Atlantic temperature series shown in the Figure (see also Delworth and Greatbach 2000; Zhang et al. 2007; Semenov and Latif 2012; Wigley and Santer 2013; Delworth et al. 2016). The subsequent cooling in the Arctic to the mid 1970s,

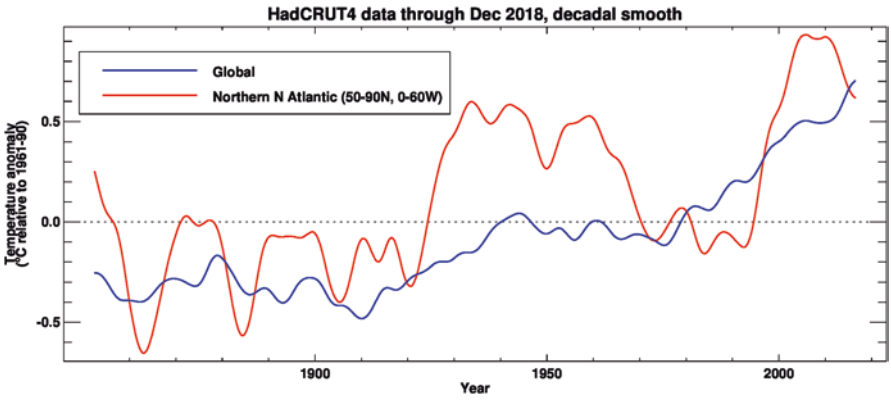

Fig. 7.1 Annual-mean temperature variations over the Atlantic Arctic compared with global-mean variations from 1850–2018. The data have been filtered with a low-pass filter to highlight changes on decadal and longer time-scales. The data are from the gridded HadCRUT3v land-plus-marine dataset (Brohan et al. 2006). (Updated February 2019 courtesy of Professor Tim Osborn, Director, Climatic Research Unit, Norwich, UK)

manifested as a levelling-off of the global trend, is largely the result of aerosol cooling associated with increased emissions of SO_2, a trend that ceased in the 1980s. Although the North Atlantic region is clearly more variable than the global record in terms of temperature, both show another strong warming trend over 1995–2005. While internally generated variability and decadal fluctuations (such as those related to ocean–atmosphere interactions) are important, longer multi-decadal time-scale changes are primarily attributable to anthropogenic forcing. There are indications of a downturn in the northern North Atlantic temperatures since about 2005. This may modulate the secular anthropogenic warming trend in the Atlantic sector of the Arctic and Subarctic in coming decades.

The climatic regimes of Iceland, Greenland and northern Norway are quite different from one another, but the climate systems that affect them are closely linked by virtue of geographic proximity. As a result of the warming effect of the Irminger Current (see Fig. 7.2) Iceland enjoys a relatively mild climate. Greenland has a true arctic climate with its surrounding waters dominated by the cold East Greenland Current. In the past, the region has experienced relatively severe ice conditions, with ports commonly closed for long periods due to winter ice and icebergs (Ogilvie 2010; Miles et al. 2014). In the early part of the twenty-first century sea ice has only

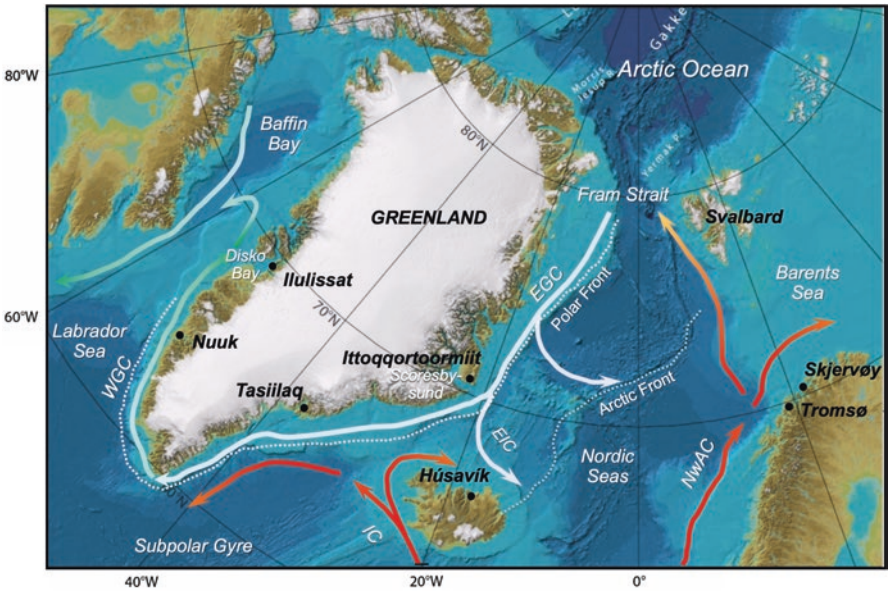

Fig. 7.2 Geographical settings and locations of ARCPATH primary focus areas. Major temperate (warm colours) and cold (cold colours) ocean currents are shown: East Greenland Current (EGC); West Greenland Current (WGC); East Icelandic Current (EIC); Irminger Current (IC); and Norwegian Atlantic Current (NwAC). The Polar front indicates the modern mean limit of polar waters and sea ice of Arctic Ocean origin. Bathymetry from the International Bathymetry Chart of the Arctic Ocean (IBCAO). (Figure courtesy of Dr Martin Miles, NORCE Norwegian Research Centre and University of Colorado-Boulder)

been a rare visitor to the coasts of Iceland. In recent years, the climate of Greenland has been marked by record warm temperatures, reduced sea ice, significant ice loss by melting, and glacier-area loss (Box et al. 2019; Andersen et al. 2019). Iceland is greening, having experienced very warm years recently, and it is possible that the country's glaciers that have always been such a dominant feature of the landscape will have disappeared within the next 200 years (Trausti Jónsson, pers. comm.). Both Iceland and Greenland are experiencing longer growing seasons for crops and vegetation in general, coupled with increased uncertainty concerning the movements and locations of fish stocks. For northern Norway, the pronounced retreat of sea ice (e.g., Onarheim et al. 2014) and increasing influence of Atlantic Water has characterized climate shifts in the region in the Barents Sea (Lind et al. 2018) and around Svalbard (Polyakov et al. 2017) to the extent that the term "Atlantification" of the Arctic was recently coined. These oceanic changes are likely to have had a substantial and direct contribution to the recent climate warming across the region (Isaksen et al. 2016; Arctic Report Card 2019).

7.5 ARCPATH Study Locations

The countries of Iceland, Greenland and Norway are linked both geographically and historically. The settlement of Iceland, primarily from Norway and the northern British Isles, began in the late-ninth century. Approximately 100 years later, small colonies of Norse people from Iceland established two settlements in southern Greenland. They also travelled annually to the Disko Bay area to hunt for prized walrus ivory. By the time Norwegian and Danish missionaries arrived in western Greenland in the early eighteenth century, the Greenland Norse had long disappeared, leaving a mystery that fascinates people to this day (Seaver 1996; Barlow et al. 1997; Ogilvie et al. 2009; Ogilvie 2016; Frei et al. 2015; Barrett et al. 2020).

Greenlanders have traditionally subsisted on marine mammals (Born et al. 2017; Nuttall 2019). This form of subsistence has also been important in Iceland, but on a far smaller scale, although the practice is clearly as old as the first settlement (Kristjánsson 1980; Perdikaris and McGovern 2008; Frei et al. 2015). Although foreign fleets have pursued large-scale whaling in Greenlandic waters in past centuries, native Greenlanders have hunted whales only for domestic use. This practice continues today, including in ARCPATH study areas.

Whaling has been significant in Norway where minke whales are still hunted under an "objection" to the International Whaling Commissions's global ban on commercial whaling, which came into effect in 1986. Commercial whaling has been conducted intermittently in Iceland for more than a century. Initially, large Norwegian whaling stations were operated from the mid-1880s until World War I, first on the Vestfirðir peninsula (northwest Iceland) and later on the east coast. By about 1912, stocks had become depleted to the extent that whaling was no longer profitable, and, in 1916, the Icelandic Parliament passed an act prohibiting all whaling. In the following decades, whale stocks gradually recovered. Whaling was

resumed on a relatively small scale in 1948 and has continued with intervals. In 2009, Icelandic authorities allowed controversial commercial whaling for a period of 5 years, with an annual quota of up to 150 fin whales and 100 minke whales. In early 2019 the Icelandic authorities decided to step up commercial whaling by allotting increased quotas for 5 years, 2019–2023, allowing the taking of 209 fin whales and 217 minke whales. However, adapting to changed conditions, Icelanders now also focus on promoting whale-watching as part of a rapidly growing tourist industry (Einarsson 2009; Huijbens and Einarsson 2018).

For the specific locations of all project components see Fig. 7.2. ARCPATH's Iceland component is primarily focused on the municipality of Norðurthing, comprising the towns of Húsavík (population 2307) and the settlements of Kópasker (population 122) and Raufarhöfn (population 186). Particular emphasis is given to Húsavík as this is where whale watching has become a major industry over the past 25 years (Einarsson 2009; Huijbens and Einarsson 2018). The surrounding area of Skjálfandi Bay is visited by several whale species including minke whales and blue whales (Rasmussen 2014). The adjacent island of Grímsey (population 86) was once an important fishing centre, but is now suffering from depopulation. In Húsavík there has been significant emphasis on alternative economic enterprises with considerable success. With a major focus on whale watching it has come to be called the "Whale watching capital of Europe". This can be interpreted as a sign of constructive adaptability and cultural flexibility on the part of its residents (Einarsson 2009, 2011a, b; Huijbens and Einarsson 2018).

A rival for this title is the region around the island of Andøya in northern Norway situated 138 km south of Tromsø by ferry. There sperm whales (*Physeter macrocephalus)* have been observed for several years. The main village on the island is Andenes (population 2694). ARCPATH has focused on this as well as the island of Skjervøya that is situated 87 km north of Tromsø by ferry. The island's main town is Skjervøy (population 2881). Both of these locations have been chosen for special study because of their similarity to Húsavík in terms of being small towns focusing on whale watching and also experiencing a growth in marine traffic with possible impacts on the marine mammals. The whales most frequently seen around Skjervøya are humpback and killer whales. This is because the herring shoals that they feed on are currently to be found there. When the herring leave and move elsewhere, as they frequently do, the whales will follow them and also leave. If this should occur in the future, it would mean an end to the current large ongoing whale-watching operations. As well as being a tourist destination, Skjervøya is dependent on the fishing industry. These study areas are of particular interest due to changes in fishing practices and a boom in marine and other forms of tourism, which may become the new economic backbone for the coastal communities involved as long as the whales and their food sources remain. These ARCPATH locations share a common denominator regarding general human ecology. They are small resource-dependent communities, in particular, with regard to access to fish stocks. They are potentially vulnerable in terms of the health of the environment they exploit, so issues of pollution and overexploitation are key.

The Greenland component has focused primarily on coastal communities in eastern Greenland. They include Ittoqqortoormiit (formerly named Scoresby) with a population of 470 as well as Tasillaq (formerly known as *Ammassalik* or *Angmagssalik)* with a current population of 2062. Ittoqqortoormiit is a small community, established in 1924 when the Danish government decided to relocate some 70 Inuit from the more southerly community of Ammassalik along with 10 Inuit from the west coast of Greenland to this location. This was part of a plan to emphasize Danish sovereignty in East Greenland.

As of 2019 ARCPATH has also focused its research efforts on the Disko Bay (in Greenlandic *Qeqertarsuup tunua*) area of western Greenland, in particular, on the towns of Ilulissat (population 4905), the island of Qeqertarsuaq (population 845) and the community of Aasiaat (population 3112). These communities all share the common twentieth-century Greenlandic experience of a rapid transformation from scattered settlements based on hunting to an urbanizing post-industrial economy (Nuttall 2019). Shared characteristics include both economic and cultural reliance on marine resources for subsistence, along with the receipt of transfer payments from the Greenlandic government. Seal and other marine-mammal hunting remain an important part of mixed-economy subsistence activities, along with a growing tourism industry which includes whale watching. In Ilulissat, there are also prospects for increased infrastructure and economic development in connection with oil and gas exploration off the west coast. In all these communities, ARCPATH is studying the effects of marine-resource governance and marine-mammal hunting practices on community viability and resilience.

ARCPATH fieldwork has been undertaken in each of the study areas in all years of the project. Although project study sites have much in common, they are also different in several ways in terms of language, history, culture. They also can vary from one another in social-ecological as well as socio-economic factors. For this reason, research approaches are slightly different for the different regions. Thus, for example, there is more emphasis on Indigenous knowledge and traditional hunting practices in the Greenland sites. Also, whale watching tourism is less developed there than for Iceland and Norway.

7.6 Areas for Investigation

As noted above, the ARCPATH project is divided into seven specific focus areas that take the form of work packages. The following paragraphs discuss each of these with special attention given to current highlights and results. The main goal of Work Package 1, *Arctic Linkages: Climate, Environmental Change, and Human Eco-Dynamics,* has been to form an historical context for the project as a whole, in that it is exploring and establishing linkages between changes in climate, social-ecological systems, and marine systems. Work has continued on analyzing past climate variations, together with adaptations to climate impacts on economic activities such as fishing and multiple use of cetaceans. At the start of the project a main focus

was on analysis of the past sea-ice record for Iceland, in particular in terms of correlations with the North Atlantic Oscillation (NAO) index and Atlantic and Pacific Ocean multi-decadal variability. As this is an example of project synthesis, the results of this work are also discussed in Chap. 19 of this volume.

The linkages between the historical and systematic instrumental data are a continuing focus of the project in Work Package 1. Emphasis has been given to temperature variations for Iceland (which correlate well with the sea-ice index) plus analyses of storminess, ecosystem services of cetaceans and fisheries in the past, and perceived adaptations to climate impacts. In particular, there has been a focus on these specific tasks: To examine correlations between fisheries and temperature changes in the North Atlantic back to ca AD 1700; and to evaluate the incidence of extreme weather events, such as increased storminess, and human adaptation responses in our study areas in the past (Ogilvie 2020). It is clear that a correlation exists between ocean temperatures and marine stocks. Although other factors were involved, it is highly likely therefore that climate was of importance for the fisheries in several respects. If the weather was particularly stormy, for example, then many lives were lost at sea, and more fishermen were drowned during cold and stormy periods such as between 1698 and 1704. Until comparatively recent times, when many different fish species began to be caught in Iceland waters due to warmer ocean temperatures, the main species caught was cod. It is a fish that is highly dependent on water temperatures for survival with 4–7 °C being optimal. During the period from 1680 to 1760, for example, when many severe years occurred, fisheries were generally poor. It is possible therefore, that the waters around Iceland became less favourable for cod reproduction and survival. There is an interesting parallel here with research from Work Package 4 which shows that blue whales and white-beaked dolphins appear to be changing their migration routes due to changing water temperatures.

The main objective of Work Package 2, *Improved Global Climate Prediction by Initialization of Arctic Sea Ice and Sea-Surface Temperatures,* has been to improve the capability for decadal climate predictions by starting the predictions from realistic ocean and sea-ice conditions. Prediction uncertainties are being partly reduced by using two different climate models EC-Earth3 and NorCPM. The ocean and sea ice have been initialized with a so-called anomaly initialization. This means that observed deviations from the mean climate are added to the mean climate of the model. This method is used because the climate that is simulated by a model differs somewhat from the observed climate, and starting a prediction from the pure raw observations leads to unwanted drifts in the model, which degrades the prediction. To clarify, initialisation refers to the method used to adjust the model to be close to the observed conditions in terms of ocean temperature and salinity, and sea-ice cover. In this way, the model is able to make a prediction of how the ocean, sea ice, and climatic conditions will evolve over the next months and years.

Regarding the sea-ice component of EC-Earth, ARCPATH uses a 5-category ice thickness module, which means that five different ice thicknesses can be represented in each grid box of the model instead of having the same ice thickness within each grid box as formerly in the project. A more advanced (non-linear) method to

link the observed to the modelled sea-ice conditions has been developed. To test the impact of the improved initialization, first test simulations with EC-Earth have been carried out. It has been found that the improved sea-ice initialization is important for the near-surface atmosphere in the first 2 years of prediction (Tian et al. 2020). The skill of decadal climate predictions based on already existing climate predictions from the CMIP5 data archive (six different models) and from the EC-Earth (v2.3) decadal experiments have been analysed (Koenigk et al. 2018). In general, only weak prediction skill is found in surface air temperature for predictions going further than 3 years into the future. The skill or accuracy of the system is estimated by performing prediction experiments for past conditions, and comparing the evolution of the predictions with what was observed. A common way to measure skill is correlation, but many others exist.

The second prediction system used in ARCPATH is the Norwegian Climate Prediction Model (NorCPM) similar to EC-Earth (see e.g., Counillon et al. 2016). This uses a multi-category sea-ice model and an advanced method to merge (assimilate) observational data into the model (Ensemble Kalman filter, EnKF). The assimilation of sea-ice concentration into the NorCPM has been implemented and tested (Kimmritz et al. 2018). It has been found that updating the multi-category sea-ice state is of great importance in reducing errors of sea-ice concentration and thickness, near-surface temperature and salinity. Further, the NorCPM is the first system demonstrating the benefit of strongly-coupled data assimilation of ocean and sea ice in a fully-coupled system. This is a method that enables data in one model component (the ocean) to correct another component of the model (sea ice). It has been found that, while assimilating only sea-surface temperatures (SSTs) already provides good skill for sea-ice extent in winter, assimilation of sea-ice concentration prolongs the skill into the summer by reducing the error of sea-ice thickness in the first year (as shown in Kimmritz et al. 2018). The added value of assimilating new observational estimates of sea-ice thickness from satellites into NorCPM has also been tested (Xie et al. 2018). It remains to be seen to what extent this improvement will lead to improved prediction skill. In tandem with Work Package 3, Work Package 2 offers a first case for performing high-resolution predictions with regional models.

The main goal of Work Package 3, *Arctic Climate Predictions and Regional Downscaling,* has been to improve climate predictions for the Arctic/Nordic Seas to the year 2030 by using high-resolution global-coupled simulations and regional downscalings. High resolution in climate models means that climate processes can be better resolved and variables can be provided at smaller spatial scales. This is especially important in regions where temperature or precipitation varies over small distances as in mountainous regions or along coastlines. The geographical locations that ARCPATH focuses on, the coastal communities of Iceland, Greenland and Norway, are exactly such regions, requiring a high spatial resolution. These regions are being affected by the complex interactions of socio-economic, biological and climatic changes. This work package aims to provide more reliable information concerning changes in the climatic variables that are relevant for livelihoods in coastal communities. In order to deliver relevant climate information on the local

scale to Work Packages 4 and 5 (see below) two strategies are being followed. The first is to perform high resolution global climate predictions (25 km resolution) and the second is to perform regional model simulations (around 10 km resolution) where predictions with ARCPATH global models standard resolution (around 100 km resolution) from Work Package 2 are used as forcing data at the boundaries of the regional model.

The period 2002–2011 was chosen for a case study of regional downscaling of the global predictions for the Nordic regions. This period includes the large observed ocean temperature changes in 2003–2004 which are likely to be linked to the movement of whales from southwestern parts to northern parts of Iceland in this year. A first ensemble member of the 2002–2011 period has been performed with NorCPM and provided for downscaling in the regional climate model called HARMONIE, known as HCLIM. The downscaling with HCLIM of this first prediction period has begun.

The main focus of Work Package 4, *Climate, Social-Ecological Systems, Cetaceans and Tourism***,** has been to analyse to what extent climate change, tourism, and industrial development puts cetaceans (and human societies dependent on their use) under increasing and unsustainable pressure. Thus there is an integrative focus on marine changes in the Arctic, with particular regard to linkages between environmental changes and changes in cetacean populations, and the growth of whale-watching tourism. Over the life of the project, social, economic and marine biological research and fieldwork has taken place in Iceland, Greenland, the seas around Svalbard and northern Norway. This includes anthropological fieldwork in Húsavík documenting present and historical multiple marine resource use, for example fishing and whale-watching activities, as well as collaboration with local authorities in terms of developing a Marine Protected Area to better manage the multiple and growing use of the seaspace of Skjálfandi Bay (Cook et al. 2020). Ethnographic fieldwork has focused on the seasonal use of marine mammals by vocational and recreational hunters in Ittoqqortoormiit in East Greenland. This involved mapping the annual hunting cycle, including the hunting of narwhal and polar bear. For northern Norway, the focus has been on the shifting relationships between migrating whales, fisheries, and tourism in Andøya and Skervøya and how research can contribute to new knowledge dialogues to develop responsible whale-watching practices (Malinauskaite et al. 2019b).

For Iceland, a key focus is on the blue whales that have have increasingly been moving north and currently come into Skjálfandi Bay every summer in June. ARCPATH has now produced a photo-identification catalogue of 148 different individuals (Madsen 2018; Madsen et al. 2019) and for the first time there are matches of the same blue whales sighted off Svalbard and from Húsavík. This possible shift might be due to warming Arctic waters and climate change. In line with ARCPATH findings it has been suggested earlier that blue whales are moving even further north for this reason (Iversen et al. 2009).

A key task in Work Package 4 has focused on social-ecological systems, ecosystem services and cetaceans in the Arctic, where the research objective is to analyse trade-offs between different ecosystem services derived from multiple uses of

cetaceans. To address this task, five research questions have been posed: (1) What is available in terms of previous research on the topic?; (2) How do people benefit from and value the ecosystem services provided by marine mammals in the Arctic?; (3) What are the different social groups that co-produce and use the ES associated with marine mammals? How are the benefits distributed between social groups within communities?; (4) How have marine mammals in the Arctic been managed to date and what are the trajectories for their future management?; What are the actors and institutions involved?; (5) How can the valuation of whale ecosystem services be used to inform decision-making processes and the governance of marine protected areas? Recent work has addressed all five research questions with fieldwork being conducted in our research locations, in particular in Húsavík and Andøya. A recent project development is the inclusion of locations in western Greenland as study areas. Fieldwork has now been undertaken in Ilullisat, Aasiaat and Disko Island.

The emphasis of Work Package 5 has been on *Marine Governance, Security and Rapid Social and Environmental Change.* Work has been concentrated on field research on fisheries governance issues, including investigating social and economic impacts of Individual Transferable Quota (ITQ) systems in coastal communities. ARCPATH research is finding serious flaws in the design of this form of marine resource governance due to significant social, economic and ecological externalities that are not sufficiently dealt with in policy design, implementations and assessments. A major publication that team member Níels Einarsson has contributed to in the *Proceedings of the National Academy of Science* (Young et al. 2018) has shown that ITQs are panacea solutions to fisheries governance that need to be reviewed due a range of negative social equity concerns as well as their lack of flexibility and sophisticated ecosystem understanding. In fisheries management—as in environmental governance more generally—regulatory arrangements that are thought to be helpful in some contexts frequently become panaceas or, in other words, simple formulaic policy prescriptions believed to solve a given problem in a wide range of contexts, regardless of their actual consequences. When this happens, management is likely to fail, and negative side effects are common. Several of the key case studies and arguments in this publication derive from ARCPATH research.

This research suggests that fisheries policy is a key driver of change in fisheries-dependent coastal communities. Thus ARCPATH is focusing on the social, cultural, environmental and economic externalities related to the introduction of the ITQ system, concentrating on Icelandic fisheries (but also considering Norway) and how this management model continues to impact people's livelihoods and human development in fishing villages, especially in terms of opportunities of small-scale and local actors regarding fishing rights. One common outcome of ITQ systems is the consolidation of fishing rights or quotas in large companies and away from small communities. This can lead to decreased access for newcomers, reduced training opportunities for youth on the remaining vessels, and increased cost of quotas as a limited commodity. The lack of job opportunities in the fishing sector causes increased rates of outmigration by youth and women, which threatens the resilience of those communities.

At the same time, ARCPATH research suggest that there continues to be an interest from youth in partaking in fisheries livelihoods and local governments are looking for options for the renewal of the fisheries workforce. ARCPATH research is leading to experimentation with programmes that increase access to fisheries for youth and newcomers such as recruitment and educational programmes, summer youth fisheries, and newcomer quotas. In the future, ARCPATH plans to undertake further research focusing on intergenerational and gender aspects and the current or future youth and newcomer cohort in Icelandic fisheries. ARCPATH is also developing several practical recommendations to enhance local and national policies towards a more sustainable fisheries management that includes options for newcomers and women, and that protects workers rights, including immigrants. These would include important considerations for human well-being and job satisfaction, the right to work, gender equality, human rights, low environmental impacts, and equity in sustainable development.

Iceland, like many other fishing nations, has mostly focused on the ecological and the economic aspect of sustainable fisheries, overlooking other ecosystem services of ocean environments such as heritage, cultural value of food items, recreation, and education. ARCPATH research is leading towards a critical investigation of the definition of sustainable fisheries. Small-scale fisheries, in particular, can provide locally-sourced food with reduced food miles, fuel costs and greenhouse gas emissions. These fisheries offer not only flexible use of ecosystem services and diverse employment but also a sense of local fate control, belonging, cultural identity and pride in the community. These are all core aspects of Arctic human development. Such environmental and social aspects of energy efficiency and quality of life are seldom considered in definitions of sustainable fisheries, but may in fact be some of the more important factors to be taken into account in future climate change mitigation. As noted above, Work Package 6 on Synthesis is not discussed here as this is the topic of Chap. 19 in this volume.

Work Package 7 has focused on the challenges of Management and Dissemination. The management structure of ARCPATH was described earlier in this chapter and does not need to be discussed further here. However, more should be said regarding dissemination. In a project such as ARCPATH, dissemination is crucial. This is because ARCPATH is of great international relevance, both because of the global significance of the Arctic, and also because of its novel approach and focus that aims at providing policy relevant and robust knowledge that will directly benefit Arctic residents. Research results, thus, have clearly defined socio-economic relevance to the national interest of Nordic countries. They should be disseminated to policy makers and stakeholder groups.

Through its research efforts, ARCPATH will facilitate planning adaptation strategies and also encourage taking advantage of new opportunities to reduce environmental and economic risks. ARCPATH brings together a strong team, experienced in collaborative studies, and situated at institutions in the forefront of Arctic research. The combined multi-disciplinary expertise of team members, covering climate and social sciences, and extending from marine biology to environmental

economics, is creating the synergistic environment needed to address the crucial issues facing northern societies.

Through the training of young scientists, ARCPATH is helping to secure the long-term capacity in this field within the Nordic region. A week-long summer school focusing specifically on ARCPATH research has already been held in Norway in July of 2018. Its focus was on *Climate Teleconnections and Predictions: Past, Present and Future* and enrolled some 30 graduate students. Lectures were provided by ARCPATH members and invited speakers. A further summer school is envisaged for 2020, in Iceland, focusing on Marine Protected Areas. As part of this course the students will travel to the Westman Islands and observe the Beluga sanctuary that is being created there (see Beluga sanctuary (2020) in references). In addition to this, courses on marine mammals have been led annually by ARCPATH team member Marianne Rasmussen from the University of Iceland's Research Centre in Húsavík.[1] ARCPATH research findings are also being disseminated through the teaching and outreach programmes of the team. In addition to these standard ways of dissemination, ARCPATH is collaborating with photographers and artists in a novel way of disseminating information regarding arctic change to the general public (Ogilvie 2017a). See e.g., the video by Andrea Sparrow of the Arctic Arts Project (Sparrow 2020) and the film and book *Out of Ice* by environmental artist Elizabeth Ogilvie (Ogilvie 2017a, b).

7.7 In Conclusion

As noted in the original ARCPATH grant application, the rapid and far-reaching changes in the Arctic will cause global effects but will first and foremost impact Arctic Nordic regions. It is thus essential that Nordic researchers combine their expertise in order to elucidate and understand these changes. ARCPATH has built a Nordic Centre of Excellence that builds on the long experience of established researchers, leading experts in their fields, as well as including many young scientists who bring fresh insights and who will help to achieve long-term Nordic added value. These goals and achievements are well established for ARCPATH.

The strong, multi-disciplinary, and collaborative group that constitutes ARCPATH is generating knowledge of high importance for development in the Arctic Region, actively creating a critical mass for success and expertise. ARCPATH team members facilitate close collaboration between disciplines such as physical sciences focusing on climate predictions, natural sciences focusing on ecology and behaviour of cetaceans and social sciences such as anthropology and economics focusing on the societal importance of cetaceans and the implications of climate change. The project therefore not only acknowledges that multiple disciplines are

[1] For information on this see http://rannsoknasetur.hi.is/summer_course

needed to identify responsible development paths for the Arctic region but is integrating them in the research.

Combining the expertise from each participating institution is facilitating important synergies in knowledge creation, and it is clear that the research conducted could not be done by each partner institution on its own. For example, by linking climatological data with the ecology and behaviour of marine mammals, ARCPATH is already drawing international talent to the Nordic region through international recruitment of senior scholars, post doctoral scholars and PhD students. The transdisciplinary approach of ARCPATH, which by definition relies on active collaboration with stakeholders, is expected to deliver significant added value for those who live in our study communities. Stakeholders have participated in the research through qualitative interviews and quantitative surveys research methods and are expected to be able to rely on the results for better-informed decision-making. Thus, for example, the project aims to deliver tangible knowledge for decision-makers contemplating the establishment of a Marine Protected Area in Skjálfandi bay in northern Iceland. An exciting and unexpected ARCPATH development is the collaboration with the initiative at the Autonomous University of Barcelona, the CER-ARCTIC Research Centre, on the two interconnected issues of Arctic social-ecological change that lend themselves well to cross-regional comparisons and knowledge transfer by the use of empirical cases. This Centre may be seen in part as a development issuing from ARCPATH. It is envisaged that, even after the end of the project, ARCPATH research goals and values will be continued through future projects.

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References

ACIA, Arctic Climate Impact Assessment. (2005). *Impacts of a warming Arctic: Arctic climate impact assessment*. Cambridge/New York: Cambridge University Press.

AHDR. (2014). In J. Nymand Larsen & G. Fondahl (Eds.), *Arctic human development report: Regional processes and global linkages*. Copenhagen: Nordic Council of Ministers.

AHDR, Arctic Human Development Report. (2004). Einarsson, N., Nymand Larsen, J., Nilsson, A., Young, O.R. (Eds.) Stefansson Arctic Institute, Akureyri.

Andersen, J. K., Fausto, R. S., Hansen, K., Box, J. E., et al. (2019). Update of annual calving front lines for 47 marine terminating outlet glaciers in Greenland (1999–2018). GEUS

Bulletin Vol 43 | e2019430202|Published online: 26 June 2019. https://doi.org/10.34194/GEUSB-201943-02-02.

Arctic Report Card. (2019). Retrieved 15 January 2019 from https://arctic.noaa.gov/Report-Card/Report-Card-2019.

Barlow, L. K., Sadler, J. P., Ogilvie, A. E. J., Buckland, P. C., Amorosi, T., Ingimundarson, J. H., Skidmore, P., Dugmore, A. J., & McGovern, T. H. (1997). Interdisciplinary investigations of the end of the Norse Western settlement in Greenland. *Holocene, 7*(4), 489–499.

Barrett, J., Boessenkool, S., Kneale, C. J., O'Connell, T. C., & Star, B. (2020). Ecological globalisation, serial depletion and the medieval trade of walrus rostra. *Quaternary Science Reviews, 229*, 106122.

Beluga Sanctuary. (2020). https://belugasanctuary.sealifetrust.org/en/about-the-sanctuary/news/a-new-hope-for-captive-whales-and-dolphins/

Born, E. W., Heilmann, A., Kielsen Holm, L., Laidre, K., & Iversen, M. (2017). *Walruses and the walrus hunt in west and Northwest Greenland: An interview survey about the catch and the climate*. Museum Tusculanum Press.

Box, J. E., Colgan, W. T. Brown, R. Wang, M. Overland, J., Walsh, J., Bhatt, U., Christensen, T., Schmidt, N., Lund, M., Parmentier, F.-J, Euskirchen, E., Romanovsky, V., Corell, R. Meier, W., Wouters, B., Mernild, S., Mård, J. Pawlak. J., & Olsen, M. (2019). Key indicators of Arctic climate change: 1971–2017. *Environmental Research Letters.* 045010 https://doi.org/10.1088/1748-9326/aafc1b

Bravo, M. T. (2019). *North pole nature and culture* (255 pp). London: Reaktion Books.

Brohan, P., Kennedy, J., Harris, I., Tett, S. F. B., & Jones, P. D. (2006). Uncertainty estimates in regional and global observed temperature changes: A new dataset from 1850. *Journal of Geophysical Research, 111*, D12106. https://doi.org/10.1029/2005JD006548.

Cochrane, P., Marshall, C. A., Garcia-Downing, C., Kendall, E., Cook, D., McCubbin, L., & Gover, R. M. (2008). Indigenous ways of knowing: implications for participatory research and community. *American Journal of Public Health, 98*(1), 22–27. Epub 2007 Nov 29.

Cook, D., Malinauskaite, L., Davíðsdóttir, B., Ögmundardóttir, H., & Roman, J. (2020). Reflections on the ecosystem services of whales and how their contribution to human well-being might be valued. *Ocean and Coastal Management*. (In Review).

Counillon, F., Keenlyside, N., Bethke, I., Wang, Y., Billeau, S., Shen, M. L., & Bentsen, M. (2016). Flow-dependent assimilation of sea surface temperature in isopycnal coordinates with the Norwegian climate prediction model. *Tellus, A, 68*, 32437. https://doi.org/10.3402/tellusa.v68.32437.

Delworth, T. L., & Greatbatch, R. J. (2000). Multidecadal thermohaline circulation variability driven by atmospheric surface flux forcing. *Journal of Climate, 13*, 1481–1495.

Delworth, T. L., Zeng, F., Vecchi, G. A., Yang, X., Zhang, L., & Zhang, R. (2016). The North Atlantic oscillation as a driver of rapid climate change in the northern hemisphere. *Nature Geoscience, 9*, 509–512.

Druckenmiller, M., Eicken, H., George, J. C., & Brower, L. (2012). Trails to the whale: Reflections of change and choice on an Inupiat icescape at Barrow, Alaska. *Polar Geography, 36*, 5–29. https://doi.org/10.1080/1088937X.2012.724459.

Einarsson, N. (2009). From good to eat to good to watch: Whale watching, adaptation and change in Icelandic fishing communities. *Polar Research, 1*, 129–138.

Einarsson, N. (2011a). *Culture, conflict and crises in the Icelandic fisheries. An anthropological study of people, Policy and Marine Resources in the North Atlantic Arctic*. Uppsala: University of Uppsala Press.

Einarsson, N. (2011b). Fisheries governance and social discourse in post-crisis Iceland: Responses to the UN human rights Committee's views in case 1306/2004. *The Yearbook of Polar Law, 3*, 479–515.

Forbes, D. L. (Ed.). (2011). *State of the Arctic Coast 2010. Scientific review and outlook*. International Arctic Science Committee, Land-Ocean Interactions in the Coastal Zone, Arctic

Monitoring and Assessment Programme, International Permafrost Association, Helmholtz Zentrum, Geesthacht, Germany, 178 pp. http://arcticcoasts.org.

Fowler, F. J., & Mangione, T. (1990). *Standardized survey interviewing: Minimizing interview-related error*. Newbury Park: Pennsylvania State University.

Fraker, M. (2013). Killer whale *(Orcinus orca)* deaths in Prince William sound, Alaska, 1985–1990. *Human and Ecological Risk Assessment, 19*(1), 28–52. https://doi.org/10.1080/10807039.2012.719385.

Frei, K. M., Coutu, A. N., Smiarowski, K., Harrison, R., Madsen, C. K., Arneborg, J., Frei, R., Guðmundsson, G., Sindbæk, S. M., Woollett, J., Hartman, S., Hicks, M., & McGovern, T. H. (2015). Was it for walrus? Viking age settlement and medieval walrus ivory trade in Iceland and Greenland. *World Archaeology, 47*(3), 439–466. https://doi.org/10.1080/00438243.2015.1025912.

Huijbens, E., & Einarsson, N. (2018). Feasting on friends: Whales, puffins and tourism in Iceland. In C. Cline (Ed.), *Tourism experiences and animal consumption-contested values, morality and ethics* (pp. 10–27). London: Routledge.

IPCC. (2014). *Climate change. The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climatic change. 1535*. Cambridge, UK and New York, USA: Cambridge University Press.

IPCC. (2018). *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* (V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield, Eds.). https://www.ipcc.ch/sr15/

Isaksen, K., Nordli, Ø., Førland, E. J., Łupikasza, E., Eastwood, S., & Niedźwiedź, T. (2016). Recent warming on Spitsbergen – Influence of atmospheric circulation and sea ice cover. *Journal of Geophysical Research Atmospheres, 121*, 11,913–11,931.

Iversen, M., Rasmussen, M. H., Cecchetti, A., Sigurðardóttur, V., Wald, E., & Vikingson, G. A. (2009). *Seasonal occurrence and potential movement of feeding area of blue whales around Iceland – Preliminary studies*. Istanbul, Turkey: ECS conference.

Kahn, M. (2016). The climate change adaptation literature. *Review of Environmental Economics and Policy, 10*(1), 166–178. https://doi.org/10.1093/reep/rev023.

Kimmritz, M., Counillon, F., Bitz, C. M., Massonet, F., Bethke, I., & Gao, Y. (2018). Optimising assimilation of sea-ice concentration in an earth system model with a multicategory sea-ice model. *Tellus, Seris A, Dynamic Meteorology and Oceanography, 70*, 1435945.

Kishigami, N. (2010). Climate change, oil and gas development and Inupiat whaling in Northwest Alaska. *Etudes Inuit Studies, 34*(1), 91–107.

Koenigk, T., Gao, Y., Gastineau, G., Keenlyside, N., Nakamura, T., Ogawa, F. Orsolini, Y., Semenov, V., Suo, L., Tian, T., Wang, T., Wettstein, J. J., & Yang, S. (2018). Impact of Arctic Sea ice variations on winter temperature anomalies in northern hemispheric land areas, *Climate Dynamic*s (published online) 1–27. https://doi.org/10.1007/s00382-018-4305-1.

Kristjánsson, L. (1980). *Íslenzkir sjávarhættir 1*. Reykjavík: Bókaútgáfa Menningarsjóðs.

Lind, S., Ingvaldsen, R. B., & Furevik, T. (2018). Arctic warming hotspot in the northern Barents Sea linked to declining sea-ice import. *Nature Climate Change, 8*, 634–639.

Madsen, M. (2018). *The migratory movement, and abundance, of the blue whales (Balaenoptera musculus) inhabiting the North-Eastern Atlantic Ocean, through photo-identification*. Master thesis: University of Copenhagen, Denmark. 119 pp.

Madsen R., Rasmussen, M. H., Olsen, M. T., Lydersen, C., Vikingson, G. A., Kovacs, K. M., Palner, M. K. H., Bertelsen, J. L., JS Jørgensen, M. S., Whittaker, M., Jacobsen, T., Scott, J., & Iversen, M. R. (2019). The migratory movements of blue whales (*Balaenoptera musculus*) inhabiting Arctic and Sub-Arctic areas of the northeast Atlantic, *Dansk Havpattedyr Symposium*, Odense, Denmark.

Malinauskaite, L., Cook, D., Davíðsdóttir, B., Ögmundardóttir, H., & Roman, J. (2019a). Willingness to pay for expansion of the whale sanctuary in Faxaflói Bay, Iceland: a contingent valuation study. *Ocean and Coastal Management*.

Malinauskaite, L., Cook, D., Davíðsdóttir, B., Ögmundardóttir, H., & Roman, J. (2019b). Ecosystem services in the Arctic: A thematic review. *Ecosystem Services, 36*, 100898.

Miles, M. W., Divine, D. V., Furevik, T., Jansen, E., Moros, M., & Ogilvie, A. E. J. (2014). A signal of persistent Atlantic multidecadal variability in Arctic sea ice. *Geophysical Research Letters, 41*. https://doi.org/10.1002/2013GL058084.

Moore, M. (2014). How we all kill whales. *ICES Journal of Marine Science, 71*, 760–763. https://doi.org/10.1093/icesjms/fsu008.

Neilson, J., Gabriele, C., Jensen, A., Kackson, K., & Straley, J. (2012). Summary of reported whale-vessel collisions in Alaskan Waters. *Journal of Marine Biology*. https://doi.org/10.1155/2012/106282.

Nuttall, M. (2019). *Climate, society and subsurface politics in Greenland: Under the great ice*. London: Taylor and Francis.

Ogilvie, A. E. J. (2010). Historical climatology, *Climatic Change*, and implications for climate science in the 21st century. *Climatic Change, 100*, 33–47.

Ogilvie, A. E. J. (2016). The Norse in Greenland. In W. Stewart (Ed.), *A fortunate land* (pp. 114–126). Pliezhausen: Offsetdruckerei Karl Grammlich GmbH.

Ogilvie, A. E. J. (2017a). A brief description of sea ice. In E. Ogilvie (Ed.), *Out of ice* (pp. 88–90). London: Black Dog Publishing.

Ogilvie, E. (2017b). *Out of ice*. London and: Black Dog Publishing. http://outofice.org.uk/book/the-film/.

Ogilvie, A. E. J. (2020). Stormy weather: Climate and sea-ice variations in the north atlantic (Iceland Sector). In Natascha Mehler (Ed.), *German voyages to the North Atlantic islands (1400–1700)*. Northern World series, Brill, Leiden. Submitted.

Ogilvie, A. E. J., Woollett, J. M., Smiarowski, K., Arneborg, J., Troelstra, S., Pálsdóttir, A., & McGovern, T. H. (2009). Seals and sea ice in medieval Greenland. *Journal of the North Atlantic, 2*, 60–80.

Onarheim, I. H., Smedsrud, L. H., Ingvaldsen, R. B., & Nilsen, F. (2014). Loss of sea ice during winter north of Svalbard. *Tellus A Dynamic Meteorology and Oceanography, 66*(1), 23 933. https://doi.org/10.3402/tellusa.v66.23933.

Overland, J. E., Wang, M., & Box, J. E. (2018a). An integrated analysis of pan-Arctic climate change. *Environmental Research Letters, 14*(3). https://doi.org/10.1088/1748-9326/aaf665.

Overland, J., Dunlea, E., Box, J. E., Corell, R., Forsius, M., Kattsov, V., Skovgård Olsen, M., Pawlak, J., Reiersen, L. O., & Wang, M. (2018b). The urgency of Arctic change. *Polar Science*. https://doi.org/10.1016/j.polar.2018.11.008.

Perdikaris, S., & McGovern, T. H. (2008). Codfish and kings, seals and subsistence: Norse marine resource use in the North Atlantic. In T. Rick & J. Erlandson (Eds.), *Human impacts on Marine environments* (pp. 157–190). UCLA Press Historical Ecology Series.

Polyakov, I. V., Pnyushkov, A. V., Alkire, M. B., Ashik, I. M., Baumann, T. M., Carmack, E. C., Goszczko, I., Guthrie, J., Ivanov, V. V., Kanzow, T., Krishfield, R., Kwok, R., Sundfjord, A., Morison, J., Rember, R., & Yulin, A. (2017). Greater role for Atlantic inflows on sea-ice loss in the Eurasian Basin of the Arctic Ocean. *Science, 356*, 285–291.

Rasmussen, M. H. (2014). The whaling versus whale-watching debate. In J. Higham & L. Bejder (Eds.), *Whale-watching: Sustainable tourism and ecological management* (pp. 81–94). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139018166.009.

Rocha, J., Peterson, G., Godin, O., & Levin, S. (2018). Cascading regime shifts within and across scales. *Science, 362*, 1379–1383. https://doi.org/10.1126/science.aat7850.

Seaver, K. A. (1996). *The frozen echo – Greenland and the exploration of North America ca. A.D. 1000–1500*. Stanford: Stanford University Press.

Semenov, V. A., & Latif, M. (2012). The early-twentieth century warming and winter Arctic Sea ice. *The Cryosphere, 6*, 1231–1237.

Sparrow. (2020). https://vimeo.com/347149339

Stroeve, J. C., Kattsov, V., Barrett, A., Serreze, M., Pavlova, T., Holland, M., & Meier, W. N. (2014). Trends in Arctic Sea ice extent from CMIP5, CMIP3 and observations. *Geophyical Research Letters, 39*, L16502. https://doi.org/10.1029/2012GL053676.

Svendsen, L., Keenlyside, N., Bethke, I., Gao, Y., & Omrani, N.-E. (2018). Pacific contribution to the early twentieth-century warming in the Arctic. *Nature Climate Change, 8*, 793–797.

Tian, T., Karami, P., Massonnet, F., Yang, S., Torben Koenigk, T., & Tim Kruschke, T. 2020. Impact of constraining sea ice volume in anomaly initialization in winter forecasts errors with the EC-Earth V3.3 Climate Prediction System. In preparation. To be submitted to *Geoscientific Model Development*.

Tokinaga, H., Xie, S.-P., & Mukougawa, H. (2017). Early 20th-century Arctic warming intensified by Pacific and Atlantic multidecadal variability. *Proceedings of the National Academy of Sciences, 114*, 6227–6232.

Wigley, T. M. L., & Santer, B. D. (2013). A probabilistic quantification of the anthropogenic component of 20th century global warming. *Climate Dynamics, 40*, 1087–1102. https://doi.org/10.1007/s00382-012-1585-8.

Xie, J., Counillon, F., & Bertino, L. (2018). Impact of assimilating a merged sea-ice thickness from CryoSat-2 and SMOS in the Arctic reanalysis. *The Cryosphere, 12*(11), 3671–3691.

Young, O. R., Webster, D. G., Cox, M. E., Raakjær, J., Blaxekjær, L. Ø., Einarsson, N., Virginia, R. A., Acheson, J., Bromley, D., Cardwell, E., Carothers, C., Eythórsson, E., Howarth, R. B., Jentoft, S., McCay, B. J., McCormack, F., Osherenko, G., Pinkerton, E., van Ginkel, R., Wilson, J. A., Rivers, L., III, & Wilson, R. S. (2018). *Proceedings of the National Academy of Sciences, 115*(37), 9065–9073. https://doi.org/10.1073/pnas.1716545115.

Zhang, R., Delworth, T. L., & Held, I. M. (2007). Can the Atlantic Ocean drive the observed multidecadal variability in Northern Hemisphere mean temperature? *Geophysical Research Letters, 34*, L02709. https://doi.org/10.1029/2006GL028683.