National Defence Défense nationale

Canadian Forces College

Collège des Forces Canadiennes

RCN's Risk Mitigation in a Changing Arctic

Lieutenant-Commander James D. Zuliani

JCSP 47

Master of Defence Studies

PCEMI 47

Maîtrise en études de la défense

Canada

CANADIAN FORCES COLLEGE – COLLÈGE DES FORCES CANADIENNES

JCSP 47 – PCEMI 47

2020 – 2021

MASTER OF DEFENCE STUDIES – MAÎTRISE EN ÉTUDES DE LA DÉFENSE

RCN RISK MITIGATION IN A CHANGING ARCTIC

By Lieutenant-Commander J.D. Zuliani

TABLE OF CONTENTS

RCN RISK MITIGATION IN A CHANGING ARCTIC

ABSTRACT

As of 2021, only 14% of the Canadian Arctic Ocean is charted to a modern or adequate standard. As climate change reduces sea-ice coverage and encourages an increase in Arctic maritime traffic, lack of adequate Arctic nautical charts will continue to threaten the safe navigation of vessels operating in the region. In turn, increased Arctic usage has driven an expectation that the Royal Canadian Navy will have a credible Arctic presence. As an organization lacking extensive experience operating in this environment, and because of the nature of the safety of navigation products available in the Arctic, the RCN faces significant risks to equipment, personnel, and credibility, that could be mitigated through the effective use of emerging technologies.

The RCN will need to continue to generate experience in Arctic operations to fulfill public and governmental expectations that it is a truly Arctic-capable navy. Lacking suitable safety of navigation products and understanding the risks to the RCN that is posed by that absence, the RCN should look to mitigate physical and credibility risks by the procurement or adaptation of technologies that can contribute to the understanding of the hydrography of the Arctic Ocean.

INTRODUCTION

Though an Arctic and maritime nation, Canada has largely ignored the "true north" in favour of other regional and international priorities. As a sparsely populated region, which in the maritime domain is effectively unusable outside of a narrow summer navigation season, there has been little domestic interest in the Arctic. Climate change, which drove regional Arctic warming and a subsequent reduction in ice cover, alarmed Canadian politicians. Physical changes to the Arctic environment increased international interest in resource exploitation, tourism, and the search for more efficient transportation routes. These emerging interests predictably influenced Canadian concerns about their northern backyard. The international debate on the nature of the Canadian Arctic Archipelago, and whether the waters Canadians thought of as *theirs* should be considered Territorial Waters, or an International Strait, prompted the Canadian government to take action to ensure that sovereignty claims of the Arctic were robust. One such action was to increase the tempo of the Canadian Armed Forces (CAF), including the Royal Canadian Navy (RCN), concerning Arctic operations. The RCN has important roles in the monitoring and enforcement of Canadian sovereignty in the Arctic as the effects of climate change further impact the region.

Despite Canada being among the more prosperous countries of the developed world, a good portion of the Canadian Arctic Ocean remains uncharted. As climate change drives increased traffic in the Arctic, lack of adequate Arctic nautical charts threatens the safe navigation of commercial vessels operating in the region. These charts, either in paper or electronic form, remain a fundamental piece of safety equipment of all maritime vessels and are mandated to be used by international organizations such as the International Maritime

Organization (IMO), the United Nations (UN) organization responsible to regulate international shipping. New charts can take years to produce from planning, surveying, and creating a product usable by mariners. Adequate chart coverage of the Canadian Arctic will not improve quickly, but in the meantime, climate change continues to lengthen the navigation season, and marine traffic continues to increase. The RCN, as one of the responsible government agencies operating in the Arctic, is exposed to both a physical risk from using those same inadequate charts and a credibility risk from the possibility of not being able to conduct the operations in the region or respond to vessels in distress.

Climate change has improved maritime access to the Canadian Arctic, which has resulted in increases in traffic and an expectation that the Royal Canadian Navy (RCN) has a credible Arctic presence. As an organization unfamiliar with operating in this environment, and because of the nature of the safety of navigation products available in the Arctic, the RCN faces significant risks to equipment, personnel, and credibility that could be mitigated through the effective use of emerging technologies.

Layout and Structure

As the Maritime Desk Officer for Geospatial-Intelligence within the Directorate General of Intelligence Policy and Partnerships (DGIPP) in Canadian Forces Intelligence Command (CFINTCOM) in Ottawa between 2017 and 2020, one of my responsibilities was to maintain the maritime geospatial intelligence relationship between the Department of National Defence (DND) and the Canadian Hydrographic Service (CHS), the Canadian Government organization responsible for hydrographic surveys and charting of Canadian waters. In maintaining that relationship, I represented DND and supported CHS at the Artic Regional Hydrographic

Commission (ARHC), a regional hydrographic commission of the International Hydrographic Organization (IHO) consisting of the five Arctic maritime nations of Canada, Russia, Norway, Denmark (representing Greenland) and the United States. The ARHC held annual conferences, each of which included a series of academic presentations discussing the difficulties hydrographers faced in the Arctic environment. These conferences in particular drew my attention to the lack of modern charts available in the Arctic and the risk that posed to mariners operating in an increasingly busy region.

The Canadian Arctic is an extreme and dynamic environment and is particularly susceptible to the effects of climate change. Based on available scientific literature, the effects of climate change have already caused shifts in maritime traffic in the Arctic. Resulting issues around sovereignty and policies issued by the Government of Canada and Department of National Defence (DND) indicate that the CAF, and thus, the RCN, will have an increasingly larger role in the region. The changing nature of the Canadian Arctic Ocean and the expectation placed upon the RCN to operate in that region involves an increased level of risk to an organization lacking the institutional experience necessary to do so because of its historical operating areas.

The RCN has historically operated on the east and west coasts of Canada and has relatively limited experience with Arctic operations. The Arctic poses a unique challenge to the RCN based on that lack of experience, and because of the risks that sea ice, dynamic weather, and lack of suitable navigation products have on all vessels operating in the environment. In particular, nautical charts in the Arctic are vastly inferior when compared to the comprehensively surveyed, modern charts produced for busier waterways. Many Arctic charts have only limited, narrow channels charted to an adequate level and are surrounded by vast uncharted areas, limiting a vessel's available room to navigate, and increasing the risk to maritime operations. The risks inherent to mariners operating in an unfamiliar and extreme environment are further increased by relying on outdated and incomplete navigation products. The RCN faces not just the same physical risks as other mariners in the region but also risks to institutional credibility when confronted with being unable to respond to a vessel in need of assistance because of those same unsuitable navigation products. The RCN can leverage existing and emerging technologies to mitigate significant physical risk and risk to credibility that an increased role in a changing and dangerous environment poses to an organization that lacks experience and adequate navigation safety products.

These technologies can be grouped into three categories depending on their intended timeline of use: immediate, pre-planned, or long-term. Immediate, or tactical-level technologies can be used by RCN vessels while deployed in the Arctic to identify channels of safe water, improving the safe operational areas of the RCN, and permitting RCN vessels to more safely respond to vessels in distress through uncharted waters. Pre-planned, or operational-level surveying efforts can be contracted and utilized prior to RCN deployments to the Arctic if the RCN identifies the area in which they intend to operate in has unsuitable chart coverage. This will improve the flexibility of the RCN in the Arctic and reduce the physical risk to the vessels. Finally, long-term or strategic-level agreements could improve the quality of charts in the Arctic over time, reducing the risk to future RCN deployments while also increasing the institutional experience. The RCN should consider utilizing some or all of these technologies to mitigate the significant physical risk, and risk to credibility that exists while operating in the Canadian Arctic.

The RCN has an increased role in the Canadian Arctic as the effects of climate change continue to alter the Arctic environment and, subsequently, the use of that environment by domestic and international parties. The Canadian Arctic is a dangerous environment that the RCN lacks the expertise and equipment to deal with. Emerging technologies can mitigate physical and credibility risks by providing the RCN with the information it needs to make informed decisions.

Literature Review

There is a great deal of literature written about the impacts of climate change, and in particular, the impacts that climate change will have on the Arctic. Summaries of available research are produced regularly by the United Nations Intergovernmental Panel on Climate Change, notably the most recent, *AR5 Synthesis Report: Climate Change in 2014*. The research and summaries all undeniably indicate that the Arctic climate is changing due to anthropogenic causes. However, how that change will impact maritime use of the Arctic is less clear. Lars-Henrik Larsen et al. describe a fictional Arctic voyage to convey the dangers of commercial use of the Arctic, highlighting the risks inherent to operating in an inhospitable and remote environment.[1] Whitney Lackenbauer and Adam Lajeunesse agree that climate change will likely cause an increase in the commercial use of the Arctic but downplay the importance of the Northwest Passage and highlight that it is unlikely the Arctic Ocean will be completely ice-free until 2070.[2] Both present possible causes as to why maritime traffic may not drastically increase as Arctic sea-ice coverage decreases. However, research conducted by Larissa Pizzolato et al. in 2014 has already shown a slight, but measurable, increase in maritime traffic over the previous

[1] Lars-Henrik Larsen et al., "Technological and Environmental Challenges of Arctic Shipping-a Case Study of a Fictional Voyage in the Arctic," *Polar Research* 35, no. 1 (2016): 1–11.

[2] Whitney Lackenbauer and Adam Lajeunesse, "On Uncertain Ice: The Future of Arctic Shipping and the Northwest Passage," *The School of Public Policy Publications (SPPP)*, December 2014, 10.

decade.[3] Subsequently, a 2017 analysis of Arctic maritime traffic by Jackie Dawson et al. showed a strong correlation between the decrease in multi-year ice and the increase in maritime traffic.[4] The quantifiable research conducted within the last decade has proven that despite the dangers of operating in the Arctic, or the forecast of continued ice coverage during the winter season for some time, use of the region has already increased. This increase in domestic and international maritime use of the Arctic has accelerated the pressure for Canada to strengthen its sovereignty in the region and resulted in policy documents clarifying the use of the CAF to that end.

Regarding the role that the CAF will have in the changing Canadian Arctic, Robert Huebert notes that if sovereignty is about protecting the security, safety, and well-being of Canadians, then there is a requirement to be able to enforce that sovereignty through the use of the CAF.[5] However, Adam Macdonald argues that sovereignty concerns in the Arctic stem not from a conventional military threat, but instead pose a constabulary challenge for Canada.[6] He contends that the normal function of a military, the application of violence against a threat to the state, will not play a role in the Arctic. He does not, however, argue against a military presence in the Arctic, but rather a restrained one. A minimal presence would accomplish the aim of providing situational awareness without overly burdening the CAF or the Arctic environment. Finally, Adam Lajeunesse agrees with Macdonald that a CAF presence in the Arctic will likely

---

[3] Larissa Pizzolato et al., "Changing Sea Ice Conditions and Marine Transportation Activity in Canadian Arctic Waters between 1990 and 2012," *Climatic Change* 123, no. 2 (March 2014): 172.

[4] Jackie Dawson et al., *Climate Change Adaptation Strategies and Policy Options for Arctic Shipping in Canada* (Ottawa: University of Ottawa, 2017), 1.

[5] Rob Huebert, *Canadian Arctic Sovereignty and Security in a Transforming Circumpolar World*, Book, Whole (Canadian International Council, 2009), 6.

[6] Adam MacDonald, *The Canadian Armed Forces and the Arctic*, Book, Whole (Conference of Defence Associations Institute, 2016), 1.

be restrained and suggests that the CAF would be best suited in a supporting role to a whole-of-government sovereignty endeavour.[7] Macdonald and Lajeunesse both identify the likely role for the RCN in the Arctic will be surveillance and supporting other government agencies. However, Michael Byers and Stewart Webb argue that due to the limited role envisioned for the CAF in the Arctic and considering the limited conventional military capabilities of the only RCN Arctic-capable vessel, the constabulary role would be better fulfilled by an armed Canadian Coast Guard (CCG).[8] This idea has merit, particularly when considering the extensive experience that the CCG possesses in Arctic operations. It does not, however, set the conditions for the RCN to generate that same Arctic experience, nor is it in line with the expectations set out by successive Conservative and Liberal governments starting in the early 2000s.

Notwithstanding the argument presented by Byers and Webb, Canadian defence policies have identified a need for an increased CAF presence in the Arctic in both the 2008 *Canada First Defence Strategy*, and 2017's *Strong, Secure, Engaged*. The former notes that "the Canadian Forces must have the capacity to exercise control over and defend Canada's sovereignty in the Arctic."[9] The most recent defence policy statement shifts the tone from one of defence to one of supporting a whole-of-government effort, in that the CAF will leverage "new capabilities to help build the capacity of whole-of-government partners to help them deliver their mandate's in Canada's North and support broader Government of Canada priorities in the Arctic

[7] Adam Lajeunesse, "The Canadian Armed Forces in the Arctic: Purpose, Capabilities, and Requirements," *The School of Public Policy Publications (SPPP)*, May 2015, 3.

[8] Michael Byers and Stewart Webb, "Titanic Blunder: Arctic/Offshore Patrol Ships on Course for Disaster" (Ottawa: Canadian Centre for Policy Alternatives, April 2013), 31.

[9] Department of National Defence, *Canada First Defence Strategy* (Ottawa: Government of Canada Publications, 2008), 8, http://publications.gc.ca/collections/collection_2010/forces/D2-261-2008-eng.pdf.

region."[10] The CAF, including the RCN, is expected to have an operational capability in the Arctic. In support of an increased CAF presence in the Arctic, Canada began procurement of six *Harry DeWolf*-class Arctic-capable patrol vessels in 2007.[11] Much of the early discussion on these vessels outside of DND highlighted their slow speed, lack of armament, and the seeming unsuitability of these ships for Arctic sovereignty patrol duties. Adam Lajeunesse summarizes many of these criticisms in his review of the Arctic and Offshore Patrol Vessel programme, but also concludes that the vessel does give Canada a platform to better prepare for the challenges that will be faced in the Arctic.[12] Adam Lajeunesse identifies the most important aspect of the introduction of the *Harry DeWolf*-class vessels, namely the RCN will once again have a vessel that was purpose-built to operate in icy Arctic waters rather than relying on ageing vessels built for an entirely different climate.

Finally, while a robust amount of literature has been written about CAF's role in the Arctic, little of that literature involves a discussion on the risks inherent in military operations, particularly in the maritime environment. The impact of challenges faced by the RCN in the Arctic are different than those faced by other mariners, and little has been written about this to date. The discussion that follows seeks to identify those risks and propose potential mitigations for the RCN to employ as their presence in the Canadian Arctic continues to increase.

[10] Department of National Defence, *Strong, Secure, Engaged: Canada's Defence Policy* (Ottawa: Government of Canada Publications, 2017), 80, http://publications.gc.ca/collections/collection_2017/mdn-dnd/D2-386-2017-eng.pdf.

[11] Byers and Webb, "Titanic Blunder," 5.

[12] Adam Lajeunesse, "Canada's Arctic Offshore and Patrol Ships (AOPS): Their History and Purpose," *Marine Policy* 124 (February 1, 2021): 13.

CHAPTER 1: CLIMATE CHANGE AND THE CANADIAN ARCTIC

Climate change is real in the 21st century. It is all around us. The topic is much debated and increasingly pressing as years go by. Climate change is in the news, it is a persistent element of international politics, it shapes internal governmental policies, and it inspires strong emotional responses on both sides of the political spectrum and from all ages. Common examples used to demonstrate the impacts of climate change usually include extreme weather events, such as the European summer heatwave in 2003, the 2011 summer draught in Texas, or the heavy rainfall of 2012 in Eastern Australia. These extreme events have been attributed to human accelerated climate change.[13] These examples, while tragic and devastating, can overshadow the impacts of climate change on isolated regions of the world. Climate change in the Canadian Arctic, particularly the Arctic ocean, continues to change how the maritime environment is used. Sovereignty considerations associated with those changes impact Canada and the RCN because as climate change drives physical changes to the Arctic environment, there will be an increased expectation from Canada that the RCN play an increasingly larger role in that environment, an environment that they have very limited historical experience in and an environment that differs from their usual operating areas.

Climate Change

While there is considerable debate as to the precise meaning of Climate Change, it is generally agreed to express a fundamental change to the environmental system because of a

[13] Mike Hulme, "Attributing Weather Extremes to 'Climate Change': A Review," *Progress in Physical Geography* 38, no. 4 (August 2014): 505.

change in one of the many factors influencing that system, for example, the concentration of green house gasses, that normally remain constant. The US National Oceanographic and Atmospheric Administration (NOAA) distinguishes between weather, described as the atmospheric state at a place and time, and climate, the long-term statistics of weather.[14] Weather changes do not necessarily signify a changing climate.[15] The concept of climate change involves long-term statistics of weather over a longer time. This is not necessarily a negative thing. The global climate has changed numerous times throughout the history of the world. The most recent and extreme example was 14,000 years ago during the Last Glacial Period when global average temperatures increased by approximately 9°C over a fifty-year period and resulted in the start of the Holocene, the current geological epoch.[16] While this trend meets the definition of climate change, it is not the same climate change as the climate change driving extreme weather events, or the same climate change at the heart of a particularly emotional political debate. The type of climate change that has immediate, relatively short-term impacts on the Arctic and requires a response from Canada and the RCN is human-influenced, or anthropogenic climate change. This is the type of climate change that makes the news, that spurs vigorous national and international debate, that national policy is written for, and that can generate intense emotions in people. That type drives Canada to reassess its interest in its Arctic region and consider utilizing the CAF to enforce its sovereignty. The impact of climate change in the Canadian Arctic denotes anthropogenic climate change.

---

[14] Congressional Research Service, "Weather and Climate Change: What's the Difference?" (Congressional Research Service, February 25, 2021), 1, https://crsreports.congress.gov/product/pdf/IF/IF11446.

[15] Ibid., 2.

[16] Jeffrey P Severinghaus and Edward J Brook, "Abrupt Climate Change at the End of the Last Glacial Period Inferred from Trapped Air in Polar Ice," *Science* 286, no. 5441 (October 29, 1999): 930.

Important to understanding the progress and impact of climate change is understanding how scientists answer the question of whether observed meteorological conditions are part of a normal cycle, or indicative of a larger shift in climate patterns. For example, some data collected has shown that the previous three decades have been the warmest since the 1400s.[17] That single data set, while concerning, does not establish whether climate change is anthropogenic or not. However, when a data set of atmospheric concentrations of greenhouse gases are included, showing that the current concentration of those gases in the atmosphere has been rising since 1850 and is currently at its highest level in the past 800,000 years, then it is possible to attribute potential causes.[18] Along with many other data sets suggesting anthropogenic climate change, the current result of decades of research is that "it is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in green house gas concentrations."[19] Climate change is real, and changes today have almost certainly been caused by humans. While the potential consequences of climate change are disastrous, but they are not uniform throughout the world. One environment, in particular, is disproportionately impacted by climate change, the ocean.

The ocean is an incredibly important engine of the global ecosystem and a critical element of continued human survival. Among other things, humans rely on such bodies of water for food and transportation. The global ocean contains over 95% of all water on the Earth and covers more than 70% of its surface.[20] The impact of climate change on the ocean has the

[17] Intergovernmental Panel on Climate Change, *Climate Change 2014 Synthesis Report: Summary for Policymakers*, 2014, 2.
[18] Ibid., 4.
[19] Ibid., 5.
[20] Intergovernmental Panel on Climate Change, *Special Report on the Ocean and Cryosphere: Summary for Policymakers*, 2019, 5.

potential to be one of the most damaging factors to human security. Coastal communities, in particular, are at risk from sea level rises due to melting ice sheets, loss of sea life habitat, and an increase in extreme weather events.[21] Based on the past seven decades of research, climate change will lead to increased ocean temperatures and ocean acidification, and a decline in available oxygen in the ocean will result in weather extremes.[22] Climate change is impacting negatively the viability of marine environments. Amongst the varied marine environments in the world, the most unique and vulnerable amongst them is being impacted the most severely, the Arctic. The oceans at Earth's polar regions are perhaps the most impacted because they are more susceptible to small changes, and those small changes can cascade, feeding back on themselves causing potentially runaway warming events.

While climate change remains a global concern, effects are being felt much more severely in the far north and far south. Climate change affects disproportionally the Arctic and Antarctic environments by warming the regions by as much as two to three times more rapidly than the rest of the world.[23] An Environment and Climate Change Canada report from 2018 assessed summer sea ice area in the Canadian Arctic was reduced by between 5% and 20% each decade since the 1960s, and that that it was very likely that there would be a continued reduction in sea ice cover in the future.[24] As particularly sensitive environments, the Arctic and Antarctic shall continue to be the hardest hit regions in the world from the impacts of climate change because of the restricted geographic ranges, or endemism of the flora, fauna, and peoples living

---

[21] Ibid.

[22] Ibid., 18.

[23] Crown-Indigenous Relations and Northern Affairs, *Canada's Arctic and Northern Policy Framework* (Ottawa: Government of Canada Publications, 2019), https://www.rcaanc-cirnac.gc.ca/eng/1560523306861/1560523330587.

[24] Environment and Climate Change Canada, *Canada's Changing Climate Report* (Ottawa: Government of Canada Publications, 2019), 198, http://publications.gc.ca/collections/collection_2019/eccc/En4-368-2019-eng.pdf.

there.[25] The vulnerability of the Arctic region to climate change is directly impacting life in the region, and also the physical features. As ice sheets melt, local wildlife is forced to adapt to new hunting strategies, which in turn has an impact on the food security of indigenous peoples like the Inuit and First Nation peoples in the Canadian Arctic. As those ice sheets melt, access to maritime transit corridors, and possible resource exploitation sites also increases, driving an ever-increasing amount of people living and working in the Arctic. Consequently, there has been a massive amount of research conducted not only on climate change but also the impacts of climate change on vulnerable regions such as the Arctic. Being able to make use of this massive amount of research becomes problematic for policy makers, who would be faced with consolidating that research to make decisions and generate policies that are consistent with current research, were it not for a United Nations (UN) organization tasked to do exactly that.

Decision-makers, when considering climate change, have a vast amount of research available to generate effective policies. Because of the environment's importance in supporting human existence and the threat that unchecked climate change poses to the environment, intensive efforts to understand causes and implications to the world have been made. To assist world governments with generating policies aligned with that vast quantity of research available, the UN created the Intergovernmental Panel on Climate Change (IPCC) with a mandate to review and produce assessments of current climate research for policy makers.[26] Five major reports published by the IPCC, with the sixth expected in 2022, have consolidated the available

---

[25] IPCC, "Summary for Policymakers," in *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*, 2018, 11.

[26] Intergovernmental Panel on Climate Change, "IPCC Factsheet: What Is the IPCC?," August 30, 2013, https://www.ipcc.ch/site/assets/uploads/2018/02/FS_what_ipcc.pdf.

climate change research and provided comprehensive and plain language summaries for policy makers to reference.[27] The common theme throughout the reports, and the primary finding from the most recent report is succinct, pointed, and identified trends that affect human habitation on the planet. It notes that human influence on the climate system is measurable, that anthropogenic greenhouse gas emissions are the highest in history, that climate changes have widespread impacts on human society, that warming of the climate since 1950 is unprecedented in history, and that the oceans have already warmed, causing the amounts of snow and ice to diminish.[28] The IPCC, through the major reports and numerous special reports, provides governments and decision-makers with an easily digestible synthesis of the research being done.

Climate change has been well established by decades of extensive and comprehensive scientific research. It is certainly, at least in part, anthropogenic, and it has a disproportionately large impact on the Arctic Ocean. Finally, a United Nations organization is tasked to collect and synthesize that massive amount of research so that it is accessible to people outside of the academic field. Climate change means that the recent historic norms for the physical environment of the Arctic will not remain constant. It has already begun to change. This change will drive a requirement for Canada to respond to that changing status, as the warming of the Arctic will result in tangible, physical changes to the Arctic Ocean and, as a result, increased use by people who have not traditionally operated in that region. The RCN will have an important role as one part of Canada's response to the changing climate because of the severity of the climate change impact on the Arctic ocean and the resulting change to Arctic maritime use patterns.

[27] Intergovernmental Panel on Climate Change, "Reports - IPCC," accessed March 19, 2021, https://www.ipcc.ch/reports/.

[28] Intergovernmental Panel on Climate Change, *Climate Change 2014 Synthesis Report: Summary for Policymakers*, 2.

Implications of Climate Change to the Canadian Arctic Ocean

Loss of ice is perhaps one of the most enduring impacts of climate change. It is an easy subject to generate interest in by using statistics of sea ice in the Canadian Arctic decreasing at a rate of 7% per decade.[29] Photographs that show historical sea ice and glacial extent compared to present conditions are alarming to those not familiar with the magnitude of ice loss caused by climate change. Media outlets pen articles about Arctic ice loss and use shocking comparison images not only to sell their products but also to help raise awareness of the changes occurring in the Arctic.[30] The changing environment in the north and images of glaciers disappearing tell a tragic story, but they generate an emotional reaction from people and play a role in increasing popular awareness of the impacts of climate change. Yet, they overlook one of the key physical implications the loss of ice has: the probability that the reduction in ice cover is likely making the problem worse than it already is. Ice cover, both on land and on the ocean, has a critical role in the moderation of temperatures in the delicately balanced Arctic climate. By reducing the amount of ice cover through anthropogenic warming, that moderating element is no longer present, and the system can accelerate towards a temperature extreme.

In a very simplified sense, for the temperature of a system to remain the same, or more correctly, for the system to be in equilibrium, the energy input to the system must equal the energy being removed. When solar radiation hits the earth, some portion of that energy is reflected into space. This reflectivity is known as the albedo, and its value varies with different

---

[29] Environment and Climate Change Canada, *Canadian Environmental Sustainability Indicators: Sea Ice in Canada* (Ottawa: Government of Canada Publications, 2019), 9, http://publications.gc.ca/collections/collection_2019/eccc/En4-144-78-2019-eng.pdf.

[30] Moira Warburton, "Canada's Last Fully Intact Arctic Ice Shelf Collapses," *Reuters*, August 6, 2020, https://www.reuters.com/article/idUSKCN2523JH.

substances. Ice and snow, for example, reflect up to 80% of the energy that it receives, whereas the ocean reflects less than 10%.[31] Since the amount of solar radiation an area receives over a year is relatively constant, as the ice melts, up to 70% more energy is absorbed by the ocean or landmass that the ice was replaced by, resulting in additional energy being inputted into the system. Additional energy in a system means an increase in temperature, which causes more ice to melt, which in turn further reduces the albedo and results in the absorption of even more solar radiation. This sequence is known as a positive feedback loop. This feedback loop in particular is known as the ice/snow albedo feedback loop. Environment and Climate Change Canada has indicated there is a very high confidence that the net feedback is positively amplifying global warming.[32] This fact means that ice loss may be a runaway process and that it will continue to melt over the coming decades. As the ice melts, more energy is absorbed, increasing the temperature of the Arctic, and further increasing the rate of ice melt. This feedback loop will result in continually decreasing ice coverage, and, in the maritime environment, an increase in the amount of navigable, ice-free water available. With an increased area of ice-free ocean for mariners to utilize, increases in the number of people who make use of the Arctic for resource exploitation and other commercial endeavours will also increase, causing a requirement for the Government of Canada to strengthen its ability to enforce environmental and other regulations on those operating inside Canadian territory.

This ice/snow albedo feedback is both causing, and the result of, decreasing sea ice in the Arctic. Along with serious implications to the region, including risks to food security of Inuit and First Nations communities and impacts on Arctic fauna, it is also driving the opening of

---

[31] Dirk Notz, "A Short History of Climate Change," *EPJ Web of Conferences* 246 (2020): 2.

[32] Environment and Climate Change Canada, *Canada's Changing Climate Report* (Ottawa: Government of Canada Publications, 2019), 43, http://publications.gc.ca/collections/collection_2019/eccc/En4-368-2019-eng.pdf.

previously unnavigable waterways. Decreased year-to-year sea-ice coverage and thickness increases open water areas and extends the navigable season by an average of five days per decade.[33] Models using the current rate of reduction of sea ice indicate that the entire Arctic Ocean will be ice-free, seasonally for the duration of the summer, by the latter half of the twenty-first century.[34] Notwithstanding the seriousness of climate change and the impact it will have on the future, reduction in sea ice and the corresponding increase in accessible Arctic water ways promotes additional usage by mariners. This is especially so for one of the most well-known Canadian sea routes, the Northwest Passage.

The Northwest Passage connects the Atlantic Ocean to the Pacific Ocean, via the Arctic Ocean. Unlike other well-known sea routes like the Strait of Hormuz, or the Strait of Gibraltar, it is not a single route but consists of several different routes, depending on the state of the ice. Today, two recognized, deep water, potential shipping routes connect through the Arctic Ocean. As shown in Figure 1.1, they are indicated as the Northwest Passage (north) and Northwest Passage (south).[35] These routes are particularly interesting to mariners transiting between the Atlantic and Pacific oceans, as they have the potential to considerably reduce the travel time, and thus the operating costs of the vessel.[36] One of the more significant operating costs that would be reduced for a vessel transiting through the Northwest Passage is the amount of fuel used when compared to the traditional route via the Panama Canal. Globally, this is an example of a negative feedback look. Less fuel is consumed overall, and thus, the ship generates less

[33] Jackie Dawson et al., "Temporal and Spatial Patterns of Ship Traffic in the Canadian Arctic from 1990 to 2015," *Arctic* 71, no. 1 (March 2018): 16.

[34] Ola M. Johannessen et al., *Sea Ice in the Arctic: Past, Present and Future* (Cham, Switzerland: Springer International Publishing AG, 2019), 402.

[35] Environment and Climate Change Canada, *Canadian Environmental Sustainability Indicators: Sea Ice in Canada*, 12.

[36] Lackenbauer and Lajeunesse, "On Uncertain Ice: The Future of Arctic Shipping and the Northwest Passage," 1.

greenhouse gas, and the impact that those greenhouse gas emissions have on the environment is reduced. Conversely, however, the increased use of the Arctic for commercial purposes places a strain on the already delicate balance because greenhouse gases previously emitted near the equator are now being directly emitted to the Arctic and the risk of direct environmental damage from accidental spills of fuel or waste increases. This results in a strong incentive for the Canadian government to ensure that its sovereignty is enforced; to ensure that Canadian environmental regulations are adhered to, and for Canada to be able to monitor and mitigate potential environmental damages.

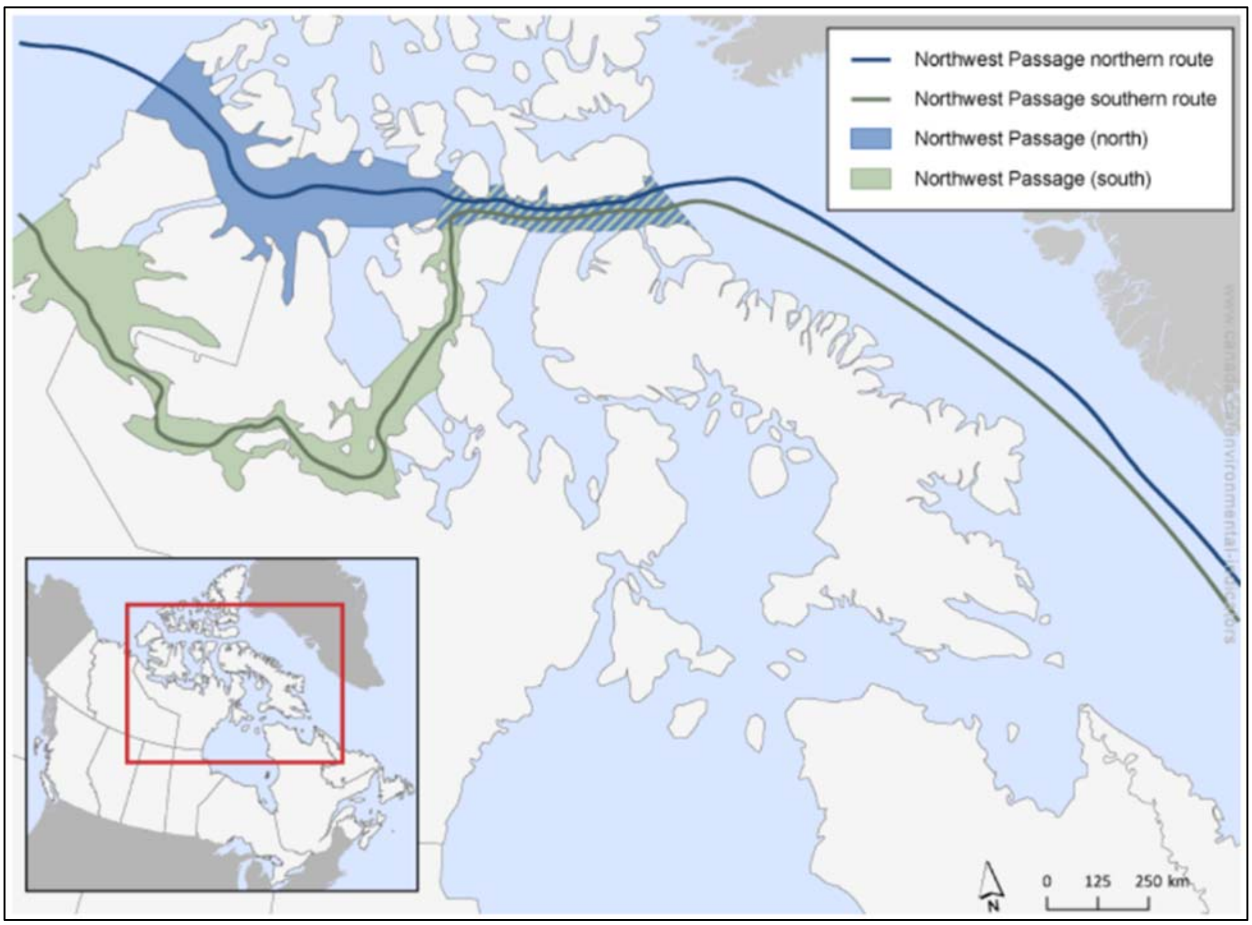

Figure 1.1 – The Northwest Passage
Source: Environment and Climate Change Canada, Canadian Environmental Sustainability Indicators: Sea Ice in Canada, 2019.

As sea ice in the Northwest Passage has diminished, the number of transits has correspondingly increased. The Scott Polar Research Institute releases an annual summary of all current and historical transits of the Northwest Passage. They recorded sixty-nine transits in the ninety-four years following the first recorded transit in 1906 by the Norwegian Sloop *Gjøa*. From 2000 to 2019, 243 recorded transits took place.[37] If the models are accurate, a decrease in the amount of ice that covers the Northwest Passage shall continue. Transit through Canadian waters becomes increasingly more desirable, and likely there will be increasing numbers of transits through the Northwest Passage.

Additionally, increases in maritime traffic are not limited to the Northwest Passage. The entire Canadian Arctic is becoming a more viable place to operate. The impact of climate change on the Arctic, loss of sea ice covering viable transportation routes and a longer navigation season point to an increase in maritime traffic in the region.[38] In the last decades, traffic doubled from 1990 to 2013 in the Canadian Arctic Ocean.[39] This trend related to more navigable waters shall continue in future and result in an increasingly large number of mariners operating in the Arctic.

As climate change continues to warm the environment in the Canadian Arctic, sea ice will decrease and navigable, ice-free water will increase. This has and will continue to drive an increase in the number of mariners operating in Canadian waters, transporting goods, exploiting resources such as fish, oil, and minerals, conducting community resupply, operating tourism vessels, and conducting scientific research. The rate of climate change and its impact on the Canadian Arctic, particularly the increase in people who will live and work in the region, is a

---

[37] R.K. Headland, "Transits of the Northwest Passage to End of the 2019 Navigation Season," Last updated March 17, 2020, https://www.spri.cam.ac.uk/resources/infosheets/northwestpassage.pdf.

[38] Dawson et al., *Climate Change Adaptation Strategies*, 43.

[39] *Ibid.*, 23.

motivating force for the Canadian government to take enforcement of its sovereignty in the region seriously. As this environment continues to change, and traffic continues to increase, there will be a continued pressure on Canada to reinforce its sovereignty claims in response to the resulting increase in maritime traffic or risk losing its ability to monitor and enforce Canadian regulations over international vessels operating in the Arctic. This, in turn, will drive an increasingly larger role for the RCN to operate in the Canadian Arctic as one part of the combined Canadian response to exerting its Arctic sovereignty.

Canadian Sovereignty in the Arctic

As international interest in the use of the Canadian Arctic increases resulting from climate change and the changing Arctic environment, so does the pressure on Canada to exert its sovereignty in the region. As one means of exerting sovereignty, the CAF, and the RCN, will have roles to play in the Arctic by contributing to a government presence and monitoring capability. However, what constitutes an effective application of sovereignty can be ambiguous, notably without an understanding of what sovereignty means. The term sovereignty is used frequently in Canadian political discourse in the context of Canada's Arctic. Current Arctic policy documents, such as 2019's *Canada's Arctic and Northern Policy Framework*, refer to Canada's enduring sovereignty being well established by historic title and the continued presence of Inuit and First Nations people but does not necessarily describe what sovereignty is.[40] Instead, the work of two noted political scientists combined with one aspect of a Canadian Military Command theory provides a useful basis for Canadian Arctic sovereignty discussions.

[40] Crown-Indigenous Relations and Northern Affairs, *Canada's Arctic and Northern Policy Framework* (Ottawa: Government of Canada Publications, 2019), https://www.rcaanc-cirnac.gc.ca/eng/1560523306861/1560523330587.

Sovereignty, in the context of the Canadian Arctic, has three important components: enforcement, recognition, and responsibility. For a nation to be able to effectively exert sovereignty in an area, they need to be able to enforce its laws and regulations, that area needs to be recognized as theirs, and because of having sovereignty over that area, they have a resulting responsibility to those inside of their borders.

The first component of Canadian Arctic sovereignty is enforcement. Professor Stephen Krasner divides sovereignty into three aspects: international legal sovereignty, the ability to enter into treaties or international organizations and the recognition by other states, domestic sovereignty, the ability for a state to regulate and control activities within their territory, and Westphalian sovereignty, the concept that a state is not subject to an external authority.[41] Concerning Canadian sovereignty enforcement in the Arctic, his domestic definition is perhaps the most useful element of the framework. For Canada to claim sovereignty over the Arctic, it must be able to enforce its laws and regulations. This is particularly important for the Canadian Arctic, as those regulations play a key role in protecting the unique environment. As maritime traffic increases, there is a corresponding increase in the risk of illegal dumping of waste, exhaust gases, accidental spills, and unquantifiable environmental pressures from marine fuel use.[42] Canada has comprehensive Arctic anti-pollution laws and regulations to protect the Arctic from these threats, but they are of little use if Canada is unable to enforce them.[43] The requirement to be able to enforce laws and regulations within a nation's territory using Krasner's domestic interpretation of sovereignty means that Canada will need a physical presence in the

---

[41] Stephen D. Krasner, "The Persistence of State Sovereignty," in *International Politics and Institutions in Time* (OUP Oxford, 2016), 41.

[42] Nicolien van Luijk, Jackie Dawson, and Alison Cook, "Analysis of Heavy Fuel Oil Use by Ships Operating in Canadian Arctic Waters from 2010 to 2018," *FACETS* 5, no. 1 (January 1, 2020): 305.

[43] Arctic Waters Pollution Prevention Act, R.S.C., c. A-12, s. 3 (1985)

Arctic. The CAF will fulfill, at least in part, that role as a representative of Canada. The ability to enforce laws and regulations within a nation's territory is the first element of Canadian sovereignty in the Arctic but is ineffective without external recognition of a nation's authority. Krasner's description of Westphalian sovereignty is useful in this context by establishing the second required element of Canadian Arctic sovereignty, recognition. His definition is echoed in the definition of sovereignty by another political scientist, Robert Jackson.

Being able to enforce regulations within your borders is one aspect of sovereignty necessary for Canada in the Arctic. For the regulations to be enforceable, however, there needs to be recognition of a sovereignty claim and shared international understanding of the area that a nation claims to be its sovereign territory. Robert Jackson proposes that sovereignty "is a legal institution that authenticates a political order based on independent states whose governments are the principal authorities both domestically and internationally."[44] The key idea in his definition is the existence of the principal authority that is recognized both domestically and internationally. Along with Krasner's concept of the state not being subject to an external authority, these describe the second element of Canadian Arctic sovereignty, recognition of its territory. A nation that claims sovereignty over an area, but is unrecognized internationally has little power to enforce its regulations without reverting to the use of force. With international recognition and an ability to enforce laws and regulations, a nation has two-thirds of the requirements to exercise sovereignty over an area. The final element, responsibility, is necessary to maintain that sovereignty as a lack of responsibility of an area degrades the strength of the first two elements, international recognition, and the enforceability of a nation's sovereignty.

[44] Robert Jackson, "Sovereignty in World Politics: A Glance at the Conceptual and Historical Landscape," *Political Studies* 47, no. 3 (August 1, 1999): 432.

Relating responsibility and sovereignty together is not a new concept. Much discussion involves the modern concept of a state's responsibility to protect people residing in other states when the foreign state is unwilling to protect its people from genocide, war crimes, ethnic cleansing, and other crimes against humanity.[45] Canadian sovereignty in the Arctic is not the same, but rather the implied responsibility to protect the people in that region they have authority over. Viewed using the command framework of Pigeau and McCann, originally meant to analyze humans in command but useful in this context, authority without responsibility results in what they refer to as minimal command, or in this case, minimal sovereignty.[46] Put in a manner more applicable to a discussion on sovereignty, if Canada claims to exercise sovereignty in the Arctic, but takes no effort to enforce or protect that claim, it is unlikely to be enforceable internationally. Taking responsibility for the area of a sovereignty claim justifies and gives a nation international recognition of its ability to enforce that claim. In the case of the Canadian Arctic, sovereignty is both the *de facto* and *de jure* authorities and responsibilities that Canada has to oversee and regulate activities conducted within the Arctic.

By utilizing all three described elements of sovereignty in the Canadian Arctic, the Canadian government strengthens its sovereignty claim, its international recognition, and ultimately improves its ability to enforce its national regulations. While the physical aspects of strengthening sovereignty involves understanding what is happening in the region through surveillance and physically enforcing regulations through a constabulary presence, the Canadian Government expresses its intent to enforce sovereignty of the Arctic through policy documents, such as the previously mentioned Arctic and Northern Policy Framework.

---

[45] Luke Glanville, "The Antecedents of 'Sovereignty as Responsibility,'" *European Journal of International Relations* 17, no. 2 (May 19, 2010): 234.

[46] Ross Pigeau and Carol McCann, "Re-Conceptualizing Command and Control," *Canadian Military Journal* 3, no. 1 (Spring 2002): 59.

Prime Minister Stephen Harper released several policy documents regarding the Arctic that laid out Canada's stance towards Canadian sovereignty claims and indicated some practical measures that Canada takes to enforce their claim. The 2009 report *Canada's Northern Strategy: Our North, Our Heritage, Our Future* notes that Canadian sovereignty would be exercised by maintaining a strong presence in the North.[47] That presence consists of "putting more boots on the Arctic tundra, more ships in the icy water, and a better eye-in-the-sky."[48] The following year, a *Statement on Canada's Arctic Foreign Policy* notes an intention to continue the operations of the Canadian Armed Forces (CAF) in the Arctic, and announces new commitments to "better protect and patrol its Arctic land, sea and sky to keep changes with the region."[49] Both documents indicate that increased CAF operational tempo would be utilized to reinforce the Canadian sovereignty claim in the Arctic as physical components of the Canadian Government's authority and responsibility in the region.

More recently, the tone of the Arctic policy documents has changed to focus on regional investments, reconciliation with the Inuit and First Nation peoples living in the Arctic, and working with international partners to solidify Canada's sovereignty claims. In 2019, Canada released the *Arctic and Northern Policy Framework,* which contained a single paragraph noting that the CAF would continue to be present in the Arctic, and conduct air, land, and sea patrols, and emphasized the use of Canadian Rangers as a surveillance capability in the region.[50] Its intent however was not to discuss the singular topic of sovereignty. Instead, it took a broader

[47] Indian and Northern Affairs, *Canada's Northern Strategy: Our North, Our Heritage, Our Future* (Ottawa: Government of Canada Publications, 2009), 9, http://publications.gc.ca/collections/collection_2016/eccc/M4-133-2016-eng.pdf.

[48] Ibid.

[49] Foreign Affairs and International Trade Canada, *Statement on Canada's Arctic Foreign Policy: Exercising Sovereignty and Promoting Canada's Northern Strategy Abroad* (Ottawa: Government of Canada Publications, 2010), 7, http://publications.gc.ca/collections/collection_2017/amc-gac/FR5-111-2010-eng.pdf.

[50] Crown-Indigenous Relations and Northern Affairs, *Canada's Arctic and Northern Policy Framework*.

approach to the challenges faced in the Arctic, including human security amongst the Inuit and First Nations peoples and the legacy that colonialism left in the region. Despite the shift in focus, successive Canadian Governments have identified the need for a physical, military presence in the Arctic to reinforce sovereignty claims, not just to prepare for a conventional military role, but also by representing effective governance and influence on the region. These requirements have been subsequently reflected in Department of National Defence policy documents.

Two key Department of National Defence policy documents are relevant to a discussion regarding current sovereignty considerations in the Arctic: the 2008 *Canada First Defence Strategy* and the more recent 2017 *Strong, Secure, Engaged: Canada's Defence Policy*. In 2008, the policy acknowledged changing weather patterns, alteration of the environment, and increases in sea traffic and economic activity.[51] The government started procurement of eight Arctic and Offshore Patrol ships. These ships would eventually join the RCN as a class of six Arctic capable *Harry DeWolf*-class offshore patrol vessels (OPV), purpose-built to increase RCN capabilities in the Arctic.[52] The updated policy in *Strong, Secure, Engaged* from 2017 maintains the importance placed upon the RCN in being able to operate in the Arctic, and reiterates the intention for a reduced number of five to six *Harry DeWolf*-class vessels to be delivered to the RCN to enhance its ability to operate in Canada's Arctic Ocean.[53] The Department of National Defence has, for at least the past decade, been aware that there is a requirement for the CAF to be operational in the Canadian Arctic and has responded by resuming annual deployments to the Arctic, which includes sending of RCN vessels to begin regaining experience in the Arctic. A more in-depth discussion of RCN experience in the Arctic is found in the next chapter.

---

[51] Department of National Defence, *Canada First Defence Strategy*, 6.
[52] Ibid., 16.
[53] Department of National Defence, *Strong, Secure, Engaged: Canada's Defence Policy*, 35.

Finally, public perception of what a navy is, or should be capable of doing is difficult to determine, especially given the confused nature of RCN operational requirements in the Arctic. Adam Lajeunesse offers a list of capabilities that the CAF should be capable of conducting in the Arctic, but notes that even when they occur, missions and exercises to the Arctic tend to receive less media coverage than large scale deployments do, and are therefore less visible to the average Canadian.[54] What a Canadian in a large inland city expects the navy to do generally, let alone in the Arctic, is in this case, less important than the presumption that the RCN is capable of operating in all three of Canada's oceans. The challenges that the RCN faces operating in the Arctic, including lack of suitable charts, and in the immediate future, lack of ships designed to operate in the Arctic, are unimportant to most Canadians. Canadians should, justifiably, expect that their navy is as capable in the Arctic as it is in the rest of the world.

Climate change is truly global in scope. No part of the world remains completely unaffected by the effects of anthropogenic climate change, and some of the most vulnerable regions of the world are facing the most severe consequences. In the case of the Canadian Arctic, climate change has resulted in reduced ice cover, exposing darker land and ocean which absorb higher amounts of the sun's warming radiation, accelerating the warming experienced there. As the ice continues to retreat, greater areas of the Canadian Arctic Ocean remain ice-free for ever lengthier periods. Thick, multi-year ice that has survived many seasons of melting has now disappeared. Any ice that reforms at the end of the summer is too thin, and the climate is too warm, to allow it to survive to the following year. The Northwest Passage, once an inspiration for Arctic explorers, is now ice-free during most summers. The Arctic, once a frozen, inhospitable place for mariners, is now an attractive transit corridor for shipping goods between

[54] Lajeunesse, "The Canadian Armed Forces in the Arctic," 1.

the Atlantic and Pacific Oceans, saving time and money. Areas covered by many meters of ice are now ice-free, permitting commercial exploration and exploitation of resources. Increased traffic in the Arctic brings with it environmental risks, from fuel spills, illegal dumping of waste, and from the impacts that the fuel marine vessels used to propel themselves through the water. Canada needs to be able to enforce its sovereignty over the Arctic to maintain the environmental security of the delicate ecosystem. And ultimately, the RCN will play a part in enforcing that sovereignty and will be required to operate as effectively in the Arctic as it can in the rest of the world. If a maritime accident occurred in the Arctic that required an immediate RCN response to which they were unable to respond, the CAF as an institution would be said to have failed and would therefore suffer a loss in reputation and credibility in the eyes of the Canadian public. As a review of the last decade of government policy papers would reveal, there has been a longstanding expectation from both the government, and the Canadian public at large, for the CAF to increase its Arctic operations capabilities based on sound scientific observations and conclusions, and therefore the inability to meet this expectation would represent a serious loss of credibility for the CAF specifically, and the Canadian government writ large.

The RCN has an increasingly larger role as part of the maritime component of Canada's assertion of Arctic sovereignty. As climate change drives environmental changes and international interest in the region grows, the RCN, inexperienced in Arctic operations, is facing significant risks both physically to their ships and personnel, as well as to their institutional credibility by operating inside Canadian territorial waters. These risks are amplified both by the lack of Arctic experience of the RCN, but also the status of navigation safety products covering a sparsely populated and until recently, infrequently used maritime area of Canada.

CHAPTER 2: LOST EXPERIENCE, ARCTIC CHARTING, AND RISK

Canadian Arctic policies since the early 2000s have highlighted the need for the CAF, and by extension, the RCN, to maintain a presence in the Canadian North. Despite being the maritime branch of the armed forces of an Arctic nation, the RCN has spent little time operating in Canada's Arctic waters. The historical operating areas of the RCN have largely been the west and east coasts of Canada, the Mediterranean, and since the First Gulf War, also the Indian Ocean and Arabian Gulf. Until recently, the few times that the RCN did include the Arctic in its operating areas, it did so only briefly, or infrequently. The RCN initially established an operating capability in Arctic waters in the 1950s with HMCS *Labrador*, before transfer to the Department of Transport, and then again for a brief period in the 1970s and 1980s before priorities once again shifted away from Arctic operations. In both cases, the RCN spent a great deal of effort generating an institutional body of experience related to the unique characteristics of Arctic operations, and in both cases, that experience was lost. It was only in 2002 that the RCN began, for the third time, to send ships regularly to operate in the Canadian Arctic. Later, in 2007, following the realization that the current ships of the RCN were unsuited for Arctic operations, the Canadian Government announced that Canada would procure a purpose-built Arctic patrol vessel, setting the stage for what was intended to be a sustained effort in maintaining a continued RCN presence in the Arctic. The knowledge gained during the previous attempts might have been lost, but the RCN once again generated experience to be able to operate in all three of Canada's oceans.

The Arctic Ocean poses challenges to mariners distinct from those in the Atlantic and Pacific oceans. Prime among these challenges is that the Arctic is an environment that is poorly, and in many areas, completely uncharted. With the increase of ice-free water during the summer season as a result of ongoing climate change, previously unpassable maritime passages have become available. These new passages, however, also pose a risk due to the lack of suitable charts and navigational aids. This risk is present not just in the RCN, but for the increasing number of civilian vessels taking advantage of the impacts that climate change is having in the Arctic. The RCN is confronted with maintaining an increasingly busy maritime picture while suffering from a lack of institutional knowledge regarding Arctic operations. They face both a physical risk to the ships and crew by operating in an area with inadequate navigation safety products, and a risk to credibility by not being able to respond effectively to a vessel in distress, or not being able to support other Government departments in the Arctic. The Canadian Arctic is a dangerous environment that the RCN lacks the expertise and support to deal with and is exposed to an increased risk to their operations as a result.

The Second World War, the Cold War, and the Middle East: Far from the Arctic

Despite Canada being a nation surrounded by three oceans, the history of RCN operations has mainly been focused on two of them, the Pacific and Atlantic oceans, and not in the Arctic Ocean. However, there have been several times that the RCN has endeavoured to gain Arctic experience, first with HMCS *Labrador* in the 1950s, then with semi-annual northern deployments in the 1970s and 1980s, and finally with Op NARWHAL and Op NANOOK series of operations in the 2000s and 2010s. In both first two attempts, the lessons learnt by those deployments were lost because they lacked continuity between them.

The RCN came into its own during the Second World War, where it spent much of its time escorting convoys transiting between North America and Europe, providing vital personnel and equipment for the Allied war effort.[55] Following the war, the RCN faced a significant reduction in size and a crisis of identity.[56] What role would a navy experienced in escorting convoys have in the post-war world? Increased threat from Soviet nuclear submarines in the late 1950s and early 1960s and the development of the North Atlantic Treaty Organization (NATO) created a capability requirement that the RCN could fill. It was decided that the RCN would concentrate its capabilities in a role that was fundamentally similar to what it did during the war, specializing in anti-submarine warfare (ASW).[57] However, instead of protecting Allied shipping from German submarines, it was to locate and track Soviet submarines. This task was conducted mainly in the North Atlantic and North Pacific oceans and would remain the primary operating area for RCN for the remainder of the 20th century.

Following the end of the Cold War, the RCN once again found itself needing to identify a role that would support the CAF and Canadian interests at sea. With the fall of the Soviet Union, subsequent reduction in the threat of the Russian Navy, and increasing tensions in the Middle East, the RCN lost its long-standing operational *raison d'être*.[58] The RCN continued to contribute to NATO standing naval task groups, but it also began supporting multinational counter-terror missions in the Middle East and responded to localized crises such as East Timor.[59] It expanded its usual operating area from the Atlantic and Pacific oceans to the South West Pacific, the Northern Indian Ocean, and the Arabian Gulf. As a result, the overwhelming

---

[55] Marc Milner, *Canada's Navy: The First Century*, 2nd ed. (Toronto: University of Toronto Press, 2009), 142.

[56] Ibid., 162.

[57] Ibid., 202.

[58] David Mugridge, "Is There Something Wrong With Our Bloody Ships Today?," *Canadian Military Journal* 10, no. 3 (Summer 2010): 65.

[59] Milner, *Canada's Navy: The First Century*, 304.

majority of collective RCN maritime operational experience lay in environments other than the Arctic.

There were several times throughout the 20th Century that the RCN began to develop some experience in the Arctic, only for it to be reset before truly being internalized by the institution.[60] In the first case, responding to US and Soviet interests in the Canadian Arctic at the onset of the Cold War, the RCN commissioned the Arctic Patrol Vessel HMCS *Labrador* in 1954 to provide the RCN with the experience to plan future operations in the Arctic.[61] It remained in the fleet for only four years, until 1958, when it was transferred to the Department of Transport and re-designated as Canadian Government Ship (CGS) *Labrador*.[62] Notably, her time in the RCN was highlighted by being the second ship to ever circumnavigate the North American continent, something that the next Arctic-capable RCN vessel HMCS *Harry DeWolf* would plan to repeat in the summer navigation season of 2021.[63] Aside from this short period, and until July 2020 with the delivery of HMCS *Harry DeWolf*, the RCN had no ships truly capable of operating in ice conditions. This was the first time, but not the last, that Arctic experience would be hard-earned and then lost in the RCN.

Following the transfer of HMCS *Labrador*, the RCN conducted no serious deployments to the Arctic until 1969. In the summer of that year, American supertanker *SS Manhattan* transited the Northwest Passage as a proof-of-concept voyage for transporting oil.[64] The Canadian public's concern about the possibility of a foreign ship transiting Canadian waters

---

[60] Thomas Juneau, Philippe Lagassé, and Srdjan Vucetic, *Canadian Defence Policy in Theory and Practice* (Cham, Switzerland: Palgrave Macmillan, 2019), 368.
[61] James A. Boutilier, *The RCN in Retrospect, 1910-1968* (Vancouver, CA: UBC Press, 1982), 287.
[62] Ibid., 306.
[63] Ibid., 294.
[64] Adam Lajeunesse and P. Whitney Lackenbauer, *Canadian Armed Forces Arctic Operations, 1941-2015: Lessons Learned, Lost, and Relearned* (Fredericton: The Gregg Centre for the Study of War & Society, 2017), 196.

without permission prompted the government to respond by enforcing its sovereignty claims in the Arctic through the CAF. The RCN began semi-annual northern deployments, at first little more than flag-waving exercises but in later years being practical operations with real objectives.[65] These northern deployments stopped with the end of the Cold War when the apparent threat to sovereignty had diminished, and once again caused years of experience in Arctic operations to be lost.

Following the second interruption of Arctic operations, RCN attempted in 2002, once again, to gain experience operating in the Arctic. The first of what would eventually be an annual exercise under the designation Op NANOOK, began with HMC Ships *Goose Bay* and *Summerside* conducting a modest northern deployment operating with the Canadian Rangers.[66] These early deployments once again highlighted the obstacles and difficulties that the Arctic environment posed to the RCN, such as the availability of fuel, the lengthy logistical train, and the difficulty in predicting ice movements.[67] These lessons had been learnt by HMCS *Labrador* in the 1950s, and again by the vessels conducting the semi-annual northern deployments in the 1970s and 1980s, but had been forgotten as those generations had been replaced by officers and sailors who knew nothing of the challenges the Arctic posed.[68] These challenges were amplified by the fact that the class of ships predominantly used to conduct Arctic deployments during this period was the *Kingston*-class. They were not designed for Arctic operations, and their limited surveillance capabilities and endurance further complicated deployments to the Arctic.

---

[65] Ibid., 197.
[66] Ibid., 307.
[67] Lajeunesse, "The Canadian Armed Forces in the Arctic…", 7.
[68] Lajeunesse and Lackenbauer, *Canadian Armed Forces Arctic Operations, 1941-2015: Lessons Learned, Lost, and Relearned*, 311.

Canada had begun to increase the maritime military presence in the Arctic to reinforce its sovereignty but had no dedicated built-for-purpose Arctic naval vessels. The *Kingston*-class vessels were originally designed to fulfil a mine warfare capability requirement, and the rest of the ships in the RCN were designed in the Cold War to participate in NATO and multinational task groups. None of the ships were designed, or meant, to conduct constabulary patrols in icy Arctic waters.[69] They lacked the hull thickness, airborne ice surveillance capabilities, and logistical endurance for continued operations in the Arctic. These exercises reinforced the limitations faced by the RCN operating in the Arctic without a ship designed for that environment.

Despite moderate efforts throughout its history to do so, and until recently, the RCN was unable to gain, and then maintain the institutional experience required for vessels operating in the Arctic, nor did it have vessels designed with the requirements of Arctic operations in mind. With the most recent resumption of Arctic deployments, and announced procurement of the *Harry DeWolf*-class Arctic and Offshore Patrol Ships, the RCN once again began gaining experience operating in the Arctic. The introduction of the *Harry DeWolf*-class ships provides the RCN with a much more capable platform in the Arctic, although it will be some time before all six ships have been completed and join the fleet, and before the crews of those vessels generate the institutional experience to operate them effectively in the Arctic.[70] Between the far more Arctic capable platforms of the *Harry DeWolf*-class and resumption of annual Arctic deployments, the increase in institutional expertise in Arctic operations will permit the RCN to operate throughout the ever-lengthening Arctic navigation season. As the RCN increases its

[69] *Ibid.*.

[70] David Pugliese, "COVID-19 Fallout: Work Begins Again on Navy's New Arctic Ships but Delivery Date Is Uncertain," *The Chronicle Herald*, June 5, 2020, https://www.thechronicleherald.ca/news/canada/covid-19-fallout-work-begins-again-on-navys-new-arctic-ships-but-delivery-date-is-uncertain-458591/.

operational tempo in the Arctic in response to the Government's requirement for an enhanced military presence in the region, experience in operating there will increase. However, while experience and capable ships will make RCN operations more effective and safer, some risks remain outside the RCN's ability to eliminate. The risk of unsuitable charts was the case in most of the world until modern hydrographic technologies permitted rapid surveying and cartographic processes to produce accurate and comprehensive charts. Until recently, most efforts in updating old charts were focused on high-volume ports and the waters surrounding them. As historically low traffic areas, the majority of the Canadian Arctic is still poorly charted. As a result, without active mitigation by the RCN, the risk posed by inadequate charts will remain extant for the RCN.

Arctic Charting and Risk to Mariners

A chart is one of the most important pieces of navigation safety equipment that a vessel carries on board. Amongst other things, it depicts the depth of water for a given area, allowing a mariner to plan a safe transit through those waters. However, a chart is only as good as the information that was used to make it. Early charts were created by hand using simple depth measuring tools, whereas accurate, modern charts are created today using multi-beam echo-sounders which can quickly collect bathymetric data on large areas of the seabed. The time and cost to collect modern multi-beam bathymetric data are not insignificant, so Hydrographic Offices (HO) often prioritize high volume areas rather than remote regions like the Arctic, to provide navigation safety products for the highest number of mariners. Charts for remote regions such as the Arctic contain dated information, are limited to narrow and specific routes, and now, with the impact that climate change is having, those regions have additional areas that could be utilized by mariners but have yet to be charted. Lack of suitable and modern navigation safety products for the Arctic poses a risk to all mariners operating in the region, and additional risk to the RCN as representatives of Canadian authority in both the physical sense of running aground, but also a risk to credibility by not being able to respond when required.

Historically, water depth was measured physically, employing a marked and weighted length of line. The hydrographer would triangulate their position based on the shoreline around them, measure the depth of water in that position, known as a *sounding*, and repeat that process as frequently as required. In a busy harbour, where the effort was economically beneficial, soundings could be taken close enough together to generate a reasonable understanding of what the bottom of the harbour looked like. In regions newly discovered by European explorers, soundings might only be taken in a single line, and the separation between soundings allows for the risk of hidden dangers to be missed. Figure 2.1 below is an example of this historical method of charting an area. The white space on the chart has not been charted. A mariner safely travelling into Wager Bay on this chart would need to plan their course to follow one of these lines. If they deviated from those planned routes, either to shorten the distance they needed to travel or to avoid ice, they risk running aground on uncharted dangers.

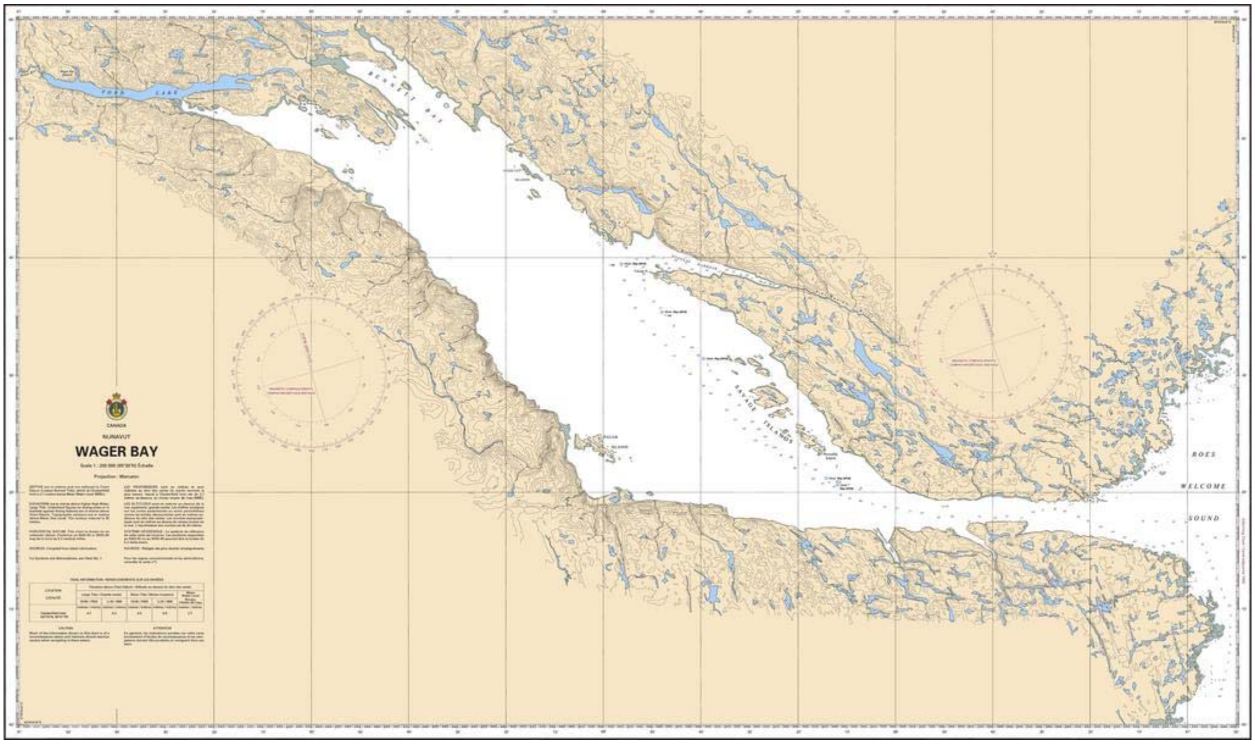

Figure 2.1 – Example of Lines of Soundings
Source: Department of Fisheries and Oceans, Canadian Hydrographic Service, 2016.

An important technological development in the world of hydrography, the science measuring the physical features of bodies of water, was the echo sounder. An echo sounder uses acoustic energy and knowledge of the sound velocity in water to measure the time it takes for a sound to be transmitted from the bottom of the survey vessel to the bottom of the ocean, and then reflected to a receiver on the survey vessel. Modern echo-sounders could send out and receive multiple, simultaneous, beams of acoustic energy. With this, they were able to generate a more comprehensive image of the bottom of the ocean. This is referred to as a multi-beam echo-sounder and is still one of the primary means that surveyors collect hydrographic data. An example of a chart created by collecting bathymetric data with a multi-beam echo-sounder is shown in Figure 2.2.

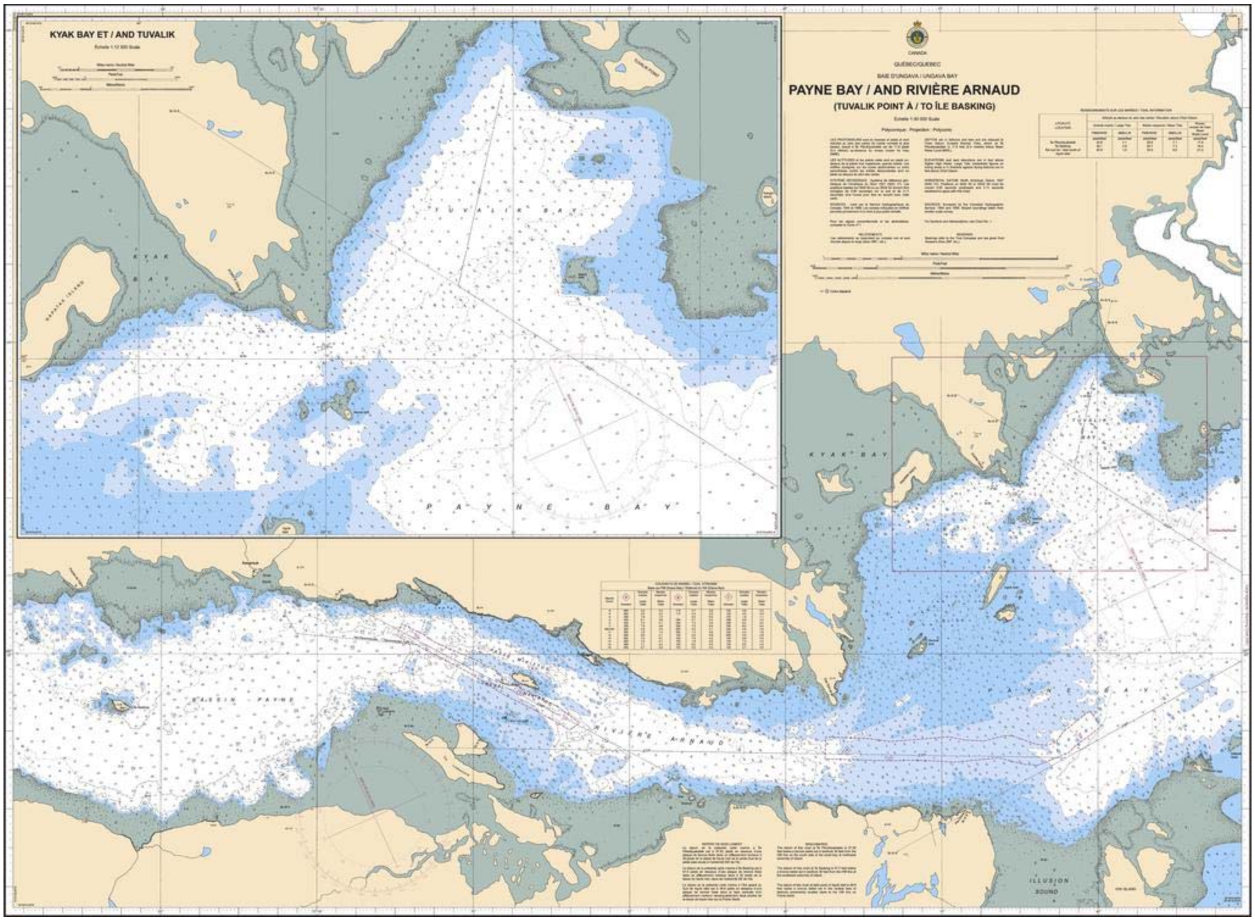

Figure 2.2 – Example of Multi-Beam Bathymetry
Source: Department of Fisheries and Oceans, Canadian Hydrographic Service, 2015.

The difference between the first chart and the second is that the mariner entering the second chart, knowing that it was created using multi-beam echo-sounders, can be confident that the depths shown on the chart are the safest. That is, while it may not be displayed on the chart, the depth between each sounding on the chart was measured and found to be no less deep than what was indicated. A mariner, knowing the depth of their vessel, could operate safely anywhere on the second chart, but is severely restricted in their ability to operate off the first chart.

Much of the Canadian Arctic Ocean is poorly charted and more closely resembles the first chart more than the second. As of 2021, only 14% of the Canadian Arctic Ocean has been charted to adequate or modern standards.[71] To prioritize the surveying efforts of CHS, and to reduce the environmental impact that maritime traffic will have on the Arctic, the Government of Canada identified a series of northern maritime transportation corridors, or low impact shipping routes that took into account historical traffic, population locations, and environmental impact.[72] These routes were identified as some of the most likely routes that a majority of vessels would be expected to use. By constraining the charting assessment to only these routes, approximately 31% of the Canadian Arctic is charted to modern or adequate standards.[73] As ice coverage diminishes from the impacts of climate change, maritime traffic in the poorly charted Arctic will increase. Vessels using outdated or incomplete charts are at risk of running aground, and this poses an increased risk to RCN vessels operating in the Arctic because they will be expected to be able to assist.

A grounding of a maritime vessel is not a trivial event. For example, in the early evening of January 13th, 2012, the Italian cruise ship *Costa Concordia* ran aground, capsized, and sank off the coast of Italy.[74] The grounding occurred on a well-charted reef, and the ship was close to populated areas with modern and robust maritime search and rescue capabilities. Despite the proximity of the search and rescue assets, thirty-two people of the over 4,000 combined

---

[71] "In general, the more recent the survey, the more accurate the data. Areas are considered adequately surveyed where the international hydrographic standards for surveying have been met. This includes continuous bottom profiles and modern radio- or satellite-positioning systems used to survey vessel positions. The latest surveys frequently consist of full bottom coverage using multi-beam sonar, sweep multi-transducer sweep systems and airborne laser bathymetry systems resulting in near 100% bottom ensonification which is considered surveyed to modern standards." Department of Fisheries and Oceans, "Arctic Charting." Last updated January 1, 2021, http://www.charts.gc.ca/arctic-arctique/index-eng.html.

[72] René Chénier et al., "Northern Marine Transportation Corridors: Creation and Analysis of Northern Marine Traffic Routes in Canadian Waters.," *Transactions in GIS* 21, no. 6 (December 2017): 1094.

[73] Department of Fisheries and Oceans, "Arctic Charting," accessed November 11, 2020, http://www.charts.gc.ca/arctic-arctique/index-eng.html.

[74] "The Wreck of the Costa Concordia," *The Economist*, January 21, 2012, Canadian Business & Current Affairs Database.

passengers and crew died, and the ship was written off as a total loss.[75] Arctic maritime tourism is growing together with the increase in maritime traffic resulting from climate change. An accident like *Costa Concordia* would be far deadlier if it occurred in the Arctic. Search and rescue response time within the Canadian Arctic is estimated to be, at best, two to eight hours.[76] As one of the most remote parts of Canada, incidents that would otherwise be a minor inconvenience can be life-threatening when the nearest assistance is hours away. Over the past two decades, there have been several examples of maritime accidents occurring in the Arctic, and while none resulted in a loss of life, that they occurred in a remote and extreme environment highlighted how hazardous Arctic operations can be.

In 2010, the vessel *Clipper Adventurer* ran aground while conducting a cruise on an uncharted shoal in the Arctic because the route the vessel followed was inadequately surveyed.[77] The vessel had stopped at Port Epworth, Nunavut and was proceeding to Kuglugtuk, Nunavut via the route indicated in Figure 2.3. The route consisted of following a single line of soundings spaced at between 800 and 1400 yards apart and had both charted and uncharted dangers on either side. This route was chosen over two other possible options to achieve an earlier arrival time at their next port of call. [78] The vessel subsequently ran aground on an unmarked shoal approximately 90 minutes after departing Port Epworth. It was a further 90 minutes before search and rescue authorities were alerted, and the ship was notified that it would be at least three

[75] Marine Casualties Investigation Body, Ministry of Infrastructure and Transports, "Cruise Ship Costa Concordia Investigation Report," n.d., 24, accessed April 14, 2021.

[76] Senate Standing Committee on Fishers and Oceans, *When Every Minute Counts: Maritime Search and Rescue* (Ottawa: Government of Canada Publications, 2018), 28 https://sencanada.ca/content/sen/committee/421/POFO/reports/MaritimeSARReport_e(forweb)_e.pdf.

[77] Transportation Safety Board of Canada, "Grounding - Passenger Vessel Clipper Adventurer, Coronation Gulf, Nunavut, 27 August 2010," Marine Investigation Report M10H0006 (Ottawa: Government of Canada Publications, 2012), 25, http://publications.gc.ca/collections/collection_2012/bst-tsb/TU3-7-10-0006-eng.pdf.

[78] Ibid., 28.

hours before fixed-wing aeronautical search and rescue resources would be able to reach them.[79] Maritime search and rescue were two days away. In this case, fortunately, there were no significant casualties, and the ship was removed from the shoal 18 days later.

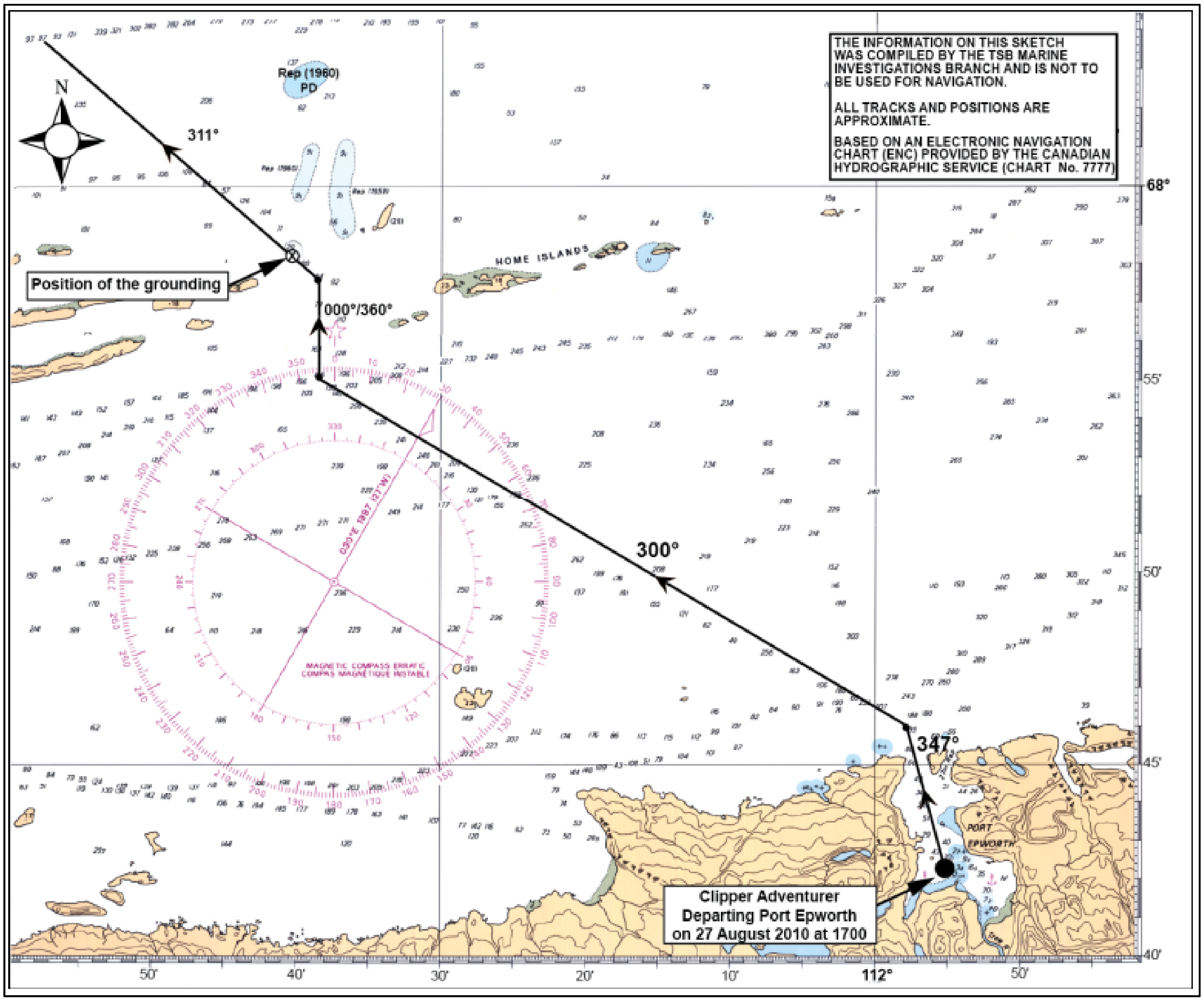

Figure 2.3 – *Clipper Adventurer* Route
Source: Transportation Safety Board of Canada, Marine Investigation, Grounding - *Clipper Adventurer*, 2012.

The *Clipper Adventurer* was not a unique event in Canadian Arctic maritime accidents. There have been several other life-threatening incidents in the past few years. The first, in 2012,

[79] Ibid., 9.

occurred when the Canadian flagged oil tanker *Nanny* ran aground on a shoal in a narrow channel in Northwest Hudson Bay.[80] It remained there for two days before floating free, and there was no loss of life or discharge of pollution. The second grounding occurred in 2018 when the passenger ship *Akademic Ioffe* conducted a cruise near Kugaaruk, Nunavut. Again, in this case, there was no loss of life but unlike *Clipper Adventurer* and *Nanny*, the vessel was abandoned, and the passengers and crew transferred to *Akademik Ioffe*'s sister ship *Akademik Sergey Vavilov*.[81] Had *Clipper Adventurer*, *Nanny*, or *Akademik Ioffe* capsized or had the crew or passengers been forced to abandon the ship without a nearby rescue vessel, they would have been exposed to the harsh Arctic environment and there very likely could have been a significant loss of life. In all three cases, the ships were fortunate that the grounding was not more serious, and that there was no loss of life. Had the RCN been nearby for any of these incidents, they would have been tasked to respond as part of their responsibilities while operating in the Arctic and would have encountered the same risks that caused the original groundings.

Risks to the RCN in the Canadian Arctic

The lack of suitable charts in the Arctic poses a potential source of risk to all mariners operating in the region. By planning routes through poorly charted areas of the Arctic, vessels like *Clipper Adventurer* chose to accept additional risk for the sake of reduced transit times and financial advantage. The RCN, when operating in the Arctic, does not have that same financial pressure that might prompt a vessel from deviating from a safely planned route. It does, however,

[80] Transportation Safety Board of Canada, "Grounding - Tanker Nanny, Chesterfield Narrows, Nunavut, 25 October 2012," Marine Investigation Report M12H0012 (Ottawa: Government of Canada Publications, 2014), 2, http://publications.gc.ca/collections/collection_2014/bst-tsb/TU3-7-12-0012-eng.pdf.

[81] Kirsten Fenn and Alyssa Mosher, "Passenger Ship That Ran Aground in Nunavut Has Been Refloated, Company Says," *The Canadian Press*, August 25, 2018, https://www.cbc.ca/news/canada/north/kugaaruk-passenger-ship-refloated-arctic-1.4799050.

have other pressures that might persuade a Commanding Officer to transit through poorly charted waters, notably responding to a vessel in distress, like *Clipper Adventurer*.

A fundamental difference between commercial ships and military vessels is while both eventually sail from one port to the next, the commercial endeavour, including transportation, tourism, resource exploitation, and scientific research, will have a route planned well in advance and generally have no reason to deviate from that route. Vessels transporting cargo have scheduled offloading times at their destination, cruise ships have timings to meet so guests can take advantage of scheduled activities, and resource exploitation vessels will transit hither and thither from the source of the resource. Commercial vessels rarely have a requirement to deviate from their originally planned route, and these planned routes can often remain unchanged for many voyages. These well-traversed routes add an extra layer of safety on a vessel's transit, as there is little risk of the depth of water changing significantly from one transit to the next.

On the other hand, while an RCN vessel might sometimes simply transit from one port to another, many operations include some sort of patrol element in them as well, and this will continue to be the case in RCN deployments to the Arctic. One of the *Harry DeWolf*-class tasks identified in its concept of use is to embark other government representatives, such as from the Royal Canadian Mounted Police (RCMP), the Canadian Border Services Agency (CBSA), the CCG, CHS, and Transport Canada (TC) so that they have a reliable platform to increase their presence in the Arctic.[82] In the case of a *Harry DeWolf*-class vessel operating in a constabulary role with RCMP or CBSA embarked, if there was a requirement to land embarked personnel or investigate a vessel operating outside of the usual high traffic, well-charted routes, there would be an additional risk to the ship by deviating into inadequately charted waters. There is an

[82] Department of National Defence, "Harry DeWolf Class Arctic / Offshore Patrol Ship Concept of Use," November 2015, 11.

additional reason why an RCN vessel might desire to deviate from a well-charted route, stemming from the nature of military operations.

In Canadian military doctrine, ten principles of war form the fundamentals of military operations: selection and maintenance of the aim, maintenance of morale, offensive action, security, surprise, concentration of force, economy of effort, flexibility, cooperation, and administration.[83] The lack of suitable charts for the Arctic impinges on two of those principles; security and flexibility. Security in *Canadian Force Joint Publication 01, Canadian Military Doctrine* "provides the freedom of action to achieve objectives … [but] does not, however, imply undue caution and avoidance of risks, as bold action is essential to success in war."[84] Lack of suitable charts in the Arctic poses a restriction on where vessels can safely operate, and thus restricts their freedom of action. The second half of the definition implies that units of the CAF, including RCN vessels, are expected to manage risk rather than avoid it. Furthermore, an RCN vessel that is restricted to a limited operating area because of insufficient charts is also limited concerning another principle of war, flexibility, because they are unable to fully, and safely, react to a developing situation.

Of all principles of war in Canadian military doctrine, flexibility may be one of the RCNs greatest strengths. In Canadian military doctrine, flexibility is required by military units so that "plans can be altered to meet changing situations and unexpected developments."[85] A warship deploys fully equipped with the capabilities of responding to a wide array of potential tasks, from conventional combat operations as an integrated part of a task group, to act as representatives of Canada in support of Defence Diplomacy, to provide situational awareness for the Canadian

---

[83] Department of National Defence, B-GJ-005-000/FP-001, *Canadian Forces Joint Publication 01: Canadian Military Doctrine* (Ottawa: DND Canada, 2009), 2–4.

[84] Ibid., 2–5.

[85] Ibid., 2–6.

government of maritime activities, to render humanitarian assistance and disaster relief, to meaningfully contribute to joint operations, and to respond to maritime search and rescue events.[86] That flexibility is severely limited when the route between where a vessel is, and where it needs to be, is uncharted. Being restricted to the high traffic routes reduces the RCN's flexibility in the Arctic and impedes their response to operational needs, such with RCMP or CBSA representatives on board. More critically, the lack of suitable charts in the Arctic also poses a significant risk to the RCN when it comes to search and rescue, for similar but potentially far more disastrous reasons.

Maritime search and rescue in Canada is a federal responsibility, and the lead authority is the Canadian Coast Guard (CCG). While search and rescue is not a primary RCN mandate, the 2013 Quadrennial Search and Rescue Review notes that with respect to maritime search and rescue, the RCN is "often called upon to assist other federal departments".[87] Furthermore, even if a vessel is not directly tasked, vessels at sea have an obligation to respond to distress signals if they can do so.[88] Finally, as one of the CAF's core missions, "provide assistance to civil authorities and nongovernmental partners in responding to international and domestic disasters or major emergencies", there is no doubt that an RCN vessel would be expected to respond to a request for aid in the Arctic.[89] An RCN vessel such as a *Harry DeWolf*-class patrol ship operating nearby would be expected and obliged to respond in the event of a maritime accident in the Arctic.[90] As increasing numbers of ships operate in the Arctic using inadequate charts and

---

[86] Department of National Defence, *Strong, Secure, Engaged: Canada's Defence Policy*, 35.

[87] Department of National Defence, *Quadrennial Search and Rescue Review* (Ottawa: Government of Canada Publications, 2013), 6, http://publications.gc.ca/collections/collection_2014/snrs-nss/D92-1-2013-eng.pdf.

[88] Senate Standing Committee on Fishers and Oceans, *When Every Minute Counts: Maritime Search and Rescue* (Ottawa: Government of Canada Publications, 2018), 14, https://sencanada.ca/content/sen/committee/421/POFO/reports/MaritimeSARReport_e(forweb)_e.pdf.

[89] Department of National Defence, *Strong, Secure, Engaged…*, 17.

[90] Department of National Defence, "Harry DeWolf Class Arctic / Offshore Patrol Ship Concept of Use," 15.

face significant risks to the lives of the passengers and crew if they run aground, the chance of a grounding in the Arctic is non-negligible. Because of increased amount of traffic and pressure on Canada to enforce its sovereignty in the Arctic, and because of the responsibility to protect those that are in their territory, the RCN will have an increasingly larger presence in the Arctic, and, as a result, be expected to assist a vessel in distress. If that vessel was aground and at risk of sinking because of lack of suitable charts, the risk remains extant for the RCN as well.

In the last decade, three high-profile groundings of commercial or scientific vessels in the Canadian Arctic occurred in remote regions. Had there been an RCN vessel nearby, there would have been an expectation that the RCN vessel would respond. In each case, assisting the vessel would have also placed the RCN vessel and its crew at risk of going aground on uncharted shoals, or would have risked the credibility of the CAF by being unable to respond. The number of these types of vessels operating in the Arctic continues to increase as climate change causes a lengthened navigation season. The quality of navigation products, while improving, is still well below the standard of the rest of Canada. As demonstrated by *Clipper Adventurer*, *Nanny*, and *Akademik Ioffe*, there is a genuine risk of vessels running aground in the Arctic, and while in those three examples there was no subsequent loss of life, there was a significant potential for adverse consequences. As new and updated charts can take several years to produce, this situation remains extant for a considerable length of time.[91] The RCN will operate in the Arctic, an area of the world where they have only a limited amount of experience, and they will be expected to be able to respond to a wide range of operational taskings, including search and rescue. The RCN faces a significant risk to their operational capability in the Arctic, both in physical risk to the ship and crew by an accidental grounding on uncharted shoals, but also a risk

[91] National Oceanic and Atmospheric Administration, "How Long Does It Take to Produce a Nautical Chart?," accessed November 29, 2020, https://oceanservice.noaa.gov/facts/chart_produce.html.

to the credibility of the RCN if they were unable to respond to a search and rescue event. The RCN can mitigate these risks by leveraging technologies that improve their ability to operate near poorly charted waters while they are deployed, technologies that improve their access to hydrographic data during the planning stages of an Arctic deployment, and technologies and agreements that will drive improved hydrographic data for all mariners, including the RCN, over the long term by utilizing data collected while at sea in the Arctic.

CHAPTER 3: RCN ARCTIC RISK MITIGATION

There are real physical risks and risks to credibility associated with RCN operations in the Arctic, because of a lack of appropriate vessels, lack of experience and expertise, and inadequate safety of navigation products. The RCN, through the procurement of the *Harry DeWolf*-class Arctic Offshore Patrol Vessels, has partially mitigated the first of these risks by utilizing a vessel designed with Arctic operations for the first time since HMCS *Labrador* in the 1950s. The residual risks from a lack of experience and inadequate safety of navigation products remain but can be mitigated through effective use of existing and emerging technologies being developed by CHS, NOAA, and other national Hydrographic Offices. These technologies all involve collection and processing of hydrographic data to increase situational awareness, and thus, reduce the risks to mariners operating in areas with poor chart coverage. By increasing the quality and quantity of hydrographic information available to RCN vessels operating in the Arctic, they can safely conduct the full range of naval operations in an area of the world that is changing and is inherently more dangerous than their traditional operating areas.

The technologies available to mitigate the risks to the RCN can be categorized into three groups related to the level at which technologies are employed, and how quickly the information they gather can be used by vessels in the Arctic. Broadly, they can be organized into tactical-level technologies, technologies that are available with limited preparation directly for a vessel to use, operational-level technologies, technologies that require some level of planning prior to operating in an area and permitting naval planners to mitigate the risk of deploying a ship to a region without adequate chart coverage, and finally, strategic-level technologies, technologies that contribute hydrographic data to the national Arctic charting effort over a longer period, resulting in a more adequately charted Canadian Arctic and reducing the risk of operating in the region for both the RCN and other maritime users. Each of these technologies plays a role in mitigating the risk to RCN operations in the Arctic.

Tactical-Level Risk Mitigation

The most accurate means of measuring the depth of water is using a multi-beam echo-sounder mounted to a platform on or under the water. At present, no ships within the RCN have an organically fitted multi-beam echosounder. A multi-beam echo-sounder can be used *in situ*, requiring no preplanning and thus would be particularly useful in maritime search and rescue operations. Multi-beam echosounders can be fitted to either look directly below a vessel, which is useful in surveying, or looking forward, to see the depth of water ahead of the vessel.[92] A forward-looking multi-beam echo-sounder is particularly useful for keeping a vessel safe when water depths are unknown, as would be the case in the great majority of Arctic waters. Either form of this technology can be utilized by the RCN to significantly reduce both physical and credibility risk by providing the crew of the vessel an accurate depth whilst operating in uncharted Arctic waters.

Unlike a traditional multi-beam echo-sounder, a forward-looking multi-beam echo-sounder is a useful addition to any RCN vessel operating in the Arctic to mitigate the risks involved in uncharted waters. A forward-looking multi-beam echo-sounder fitted to a *Harry DeWolf*-class vessel would give the vessel an accurate and instant determination of the depth

[92] R. Glenn Wright and Michael Baldauf, "Hydrographic Survey in Remote Regions: Using Vessels of Opportunity Equipped with 3-Dimensional Forward-Looking Sonar," *Marine Geodesy* 39, no. 6 (November 1, 2016): 442.

ahead of the ship, allowing travel into uncharted waters in response to a maritime search and rescue event, or in support of embarked other governmental department representatives.[93] This would nearly eliminate the possibility of an RCN vessel suffering a grounding similar to *Clipper Adventurer*. This technology is fitted to the hull of the vessel, so would require a docking period to be incorporated into the ship. A traditional multi-beam echo-sounder, on the other hand, could be utilized by vessels in the Arctic at a minimal cost by utilizing a second vessel to scout ahead of the ship.

As a traditional multi-beam echo-sounder only shows the depth of water directly beneath a vessel, fitting one directly to a vessel operating in the Arctic would require the ship to observe trends in the depth to identify risks to the ship. If, however, the multi-beam echo-sounder was fitted to a smaller vessel ahead of the ship, they could use the data from the multi-beam echo-sounder ahead of the ship and conduct a "lead through", guiding the larger vessel through uncharted waters. This was a commonly exercised procedure for mine warfare and would be similar in execution for Arctic navigation.[94] The use of a multi-beam echo-sounder embarked on a smaller vessel ahead of the ship would permit the RCN to mitigate the risk involved in responding to a search and rescue event through inadequately charted waters. There has been a great deal of research conducted on the use of autonomous vessels, but the RCN could utilize the existing boats embarked on their vessels fitted with a multi-beam echo-sounder to accomplish the same task and provide a great deal of flexibility to the vessel when operating near inadequately charted waters.[95]

---

[93] Ibid., 443.

[94] Nikki Smith, "Joint Warrior 10-1 Kicks Off with Fast-Paced Training" (Washington: Federal Information & News Dispatch, April 13, 2010).

[95] Damian Manda, "Development of Autonomous Surface Vessels for Hydrographic Survey Applications," *ProQuest Dissertations and Theses* (Master's thesis, University of New Hampshire, 2016), 106.

The downside to the use of the technologies is the cost. The equipment and training to maintain the equipment do not exist in the RCN. The equipment would need to be procured and training integrated into the existing system. The engineering change involved in fitting a forward-looking multi-beam echo-sounder is significant, but the benefits to operational safety for vessels operating in the Arctic are unmatched by any other technology. This change would permit a *Harry DeWolf*-class vessel to operate anywhere there was sufficient depth to do so, regardless of the quality of charts, and remain safe while doing so. Until a forward-looking multi-beam echo-sounder could be added, the use of a traditional multi-beam echo-sounder fitted on a smaller vessel like the currently embarked ship's boat would significantly improve an RCN vessel's situational awareness and permit them to operate in uncharted areas. These technologies present a massive operational capability improvement over what is currently available to RCN vessels and would reduce the physical risk to the ship and crew, and the credibility risk of the RCN being unable to fully operate in the Arctic.

Operational-Level Risk Mitigation

With additional planning in advance of Arctic deployments, the risk to RCN operations resulting from inadequate nautical charts and a lack of experience can also be mitigated using commercially contracted surveying technologies, such as airborne LIDAR bathymetry and satellite-derived bathymetry. Due to the length of time involved with these technologies to obtain and process the data, these methods would be more suited to an operational level planning effort, where naval planners intending to deploy RCN vessels to an uncharted area could contract a survey in advance of the deployment so that the vessel arrives in the Arctic with the information to mitigate the risk of inadequate charts.

LIDAR, or light detection and ranging, is the technology of using a laser to measure range.[96] When used to collect bathymetric data, it involves two separate lasers mounted to an aerial platform, a red laser that reflects off the surface of the water, and a blue-green laser that penetrates the water and reflects off the bottom of the ocean.[97] The depth of water is the difference in measurements between the two. Satellite-derived bathymetry is a similar process to LIDAR but uses satellite data and image processing to determine the depth rather than pulsed laser returns.

The effectiveness of airborne LIDAR bathymetry can be up to 50m but depends heavily on the clarity of the water.[98] A water column full of particulate matter will interrupt the blue-green laser measuring the ocean bottom and result in inaccurate readings.[99] The Arctic can be a difficult environment to obtain water depths from airborne LIDAR bathymetry because of that, due to the high turbidity in some areas from ice melt runoff.[100] Despite this challenge, both NOAA and CHS have contracted successful airborne LIDAR bathymetric surveys in the Arctic.[101]

Both airborne LIDAR bathymetric surveys and satellite-based bathymetric surveys have been successfully conducted by CHS in Arctic environments and have been proven to be a

---

[96] National Oceanic and Atmospheric Administration, "What Is Lidar?," accessed November 29, 2020, https://oceanservice.noaa.gov/facts/lidar.html.

[97] Department of Fisheries and Oceans, "Acquiring Hydrography Data," January 24, 2020, https://www.dfo-mpo.gc.ca/science/hydrography-hydrographie/data-acquisition-eng.html.

[98] Ibid.

[99] Yves Pastol, "Use of Airborne LIDAR Bathymetry for Coastal Hydrographic Surveying: The French Experience," *Journal of Coastal Research*, 2011, 6.

[100] Lars Chresten Lund-Hansen et al., "Summer Meltwater and Spring Sea Ice Primary Production, Light Climate and Nutrients in an Arctic Estuary, Kangerlussuaq, West Greenland," *Arctic, Antarctic, and Alpine Research* 50, no. 1 (January 1, 2018): 9.

[101] Hydro International, "CHS Contracts for Airborne Lidar Bathymetry," *Hydro International*, September 24, 2013.

reasonably accurate alternative to conventional surface surveying techniques.[102] While these techniques are only able to accurately identify depths to 15m, this is more than sufficient to identify potential dangers and reduce the risk to RCN vessels operating in the Arctic. If an RCN vessel planned to operate in, or near, an area of the Arctic that was poorly charted, a contracted LIDAR or satellite-derived bathymetric survey could identify any potential dangers to the ship and greatly reduce the risk of the ship operating in those waters. Furthermore, with close collaboration with CHS, data collected by these surveys contributes to CHS charting efforts in the Arctic, which is the third and final technological risk mitigation method for the RCN.

Strategic-Level Risk Mitigation

Long-term mitigation to the risk of inadequate nautical charts and lack of experience can be achieved by the RCN's contribution to the Arctic surveying efforts of CHS. The national responsibility to chart Canadian waters rests with the Department of Fisheries and Oceans (DFO), under the *Ocean's Act*, and is conducted through CHS.[103] Unlike other nations where the defence department and navy play a key role as a hydrographic services provider, such as the United Kingdom and the United Kingdom Hydrographic Office, charting in Canada is not within the scope of responsibility for the RCN.[104] However, there is an internationally recognized mechanism for hydrographic offices, including CHS, to collect hydrographic data from vessels that are not designed to conduct hydrographic surveys, and which do not have an embarked hydrographer onboard. This mechanism greatly improves the data collection capacity of smaller

---

[102] René Chénier et al., "Bathymetric Photogrammetry to Update CHS Charts: Comparing Conventional 3D Manual and Automatic Approaches," *ISPRS International Journal of Geo-Information* 7, no. 10 (October 2018): 11.

[103] Ocean's Act, R.S.C., c. 31, s. 42 (1996)

[104] M. W. Eelhart, "Charting the Future: The Need for Naval Hydrography" (Joint Command and Staff Program Course Paper, Canadian Forces College, 2013), 14.

national hydrographic offices like CHS and can have an even larger impact in areas like the Arctic, where maritime traffic is increasing but vast areas of poorly charted waters still exist. The RCN can leverage this mechanism to assist CHS in improving Arctic nautical charts by collecting and submitting hydrographic data from Arctic operations. The direct, long-term benefit to the RCN is resulting improvement of CHS-produced nautical charts, reducing RCN reliance on the previously identified tactical and operational level technologies to mitigate physical and credibility risks in the Arctic.

The IHO refers to the non-conventional collection of bathymetric data from vessels other than hydrographic vessels while engaged in routine maritime operations as "crowdsourced bathymetry."[105] Crowdsourced bathymetry utilizes the otherwise untapped resource of vessels equipped with echo sounders and satellite-based positioning systems who voluntarily feed collected bathymetric data into the relevant hydrographic office, thereby improving the quality of data available to create and update nautical charts.[106] CHS has utilized crowdsourced bathymetry collected in the Canadian Arctic to inform and augment their work. The RCN is well placed to assist CHS in this endeavour. By collecting hydrographic data and submitting it to CHS, the RCN can improve the status of Arctic charting by both confirming currently charted information, and by expanding the areas in which CHS has data available. For example, if the RCN utilized one of the technologies discussed previously to proceed through an uncharted area, and collected that data while doing so, that data would then be available to CHS to produce better quality charts. Subsequent RCN operations in the area would have more accurate charts to operate off. By participating in the CHS crowdsourced bathymetry project, the RCN can make a measurable

[105] International Hydrographic Organization, "B-12 Guidance on Crowdsourced Bathymetry" (International Hydrographic Organization, January 2020), 3, https://iho.int/uploads/user/pubs/bathy/B_12_Ed2.0.3_2020.pdf.

[106] Ibid., 16.

difference in the quality of Arctic charts for future operations and reduce the risk to the RCN in those future operations as a result.

Furthermore, cooperation between the RCN and CHS is not a new initiative. Since the most recent return to Arctic operations and for several years, the RCN has collected hydrographic data for CHS using an externally mounted multi-beam echo sounder fitted to *Kingston*-class vessels operating in the Arctic during Operation NANOOK.[107] This was not crowdsourced bathymetry, as it involved embarkation of a dedicated CHS hydrographer onboard the vessel to process the information, but it demonstrated a willingness by the RCN to contribute to the effort to adequately chart the Arctic.

There are challenges with the RCN utilizing crowdsourced bathymetry, both from the CHS perspective in the quality of data collected and from the RCN perspective of a lack of mandate. All hydrographic data is not the same. Crowdsourced bathymetry suffers from a potential problem of quality control. Without a trained hydrographer on board, many of the variables involved in measuring the depth of water accurately can be uncertain. For example, the type of equipment, sensor offsets and calibrations, and water conditions at the time of measurement can contribute to unknown quality of data.[108] However, those variables can, to an extent, be managed, and resulting data is of more use to hydrographic offices and mariners than no data at all.[109] Crowdsourced bathymetry may not be the optimal solution to the lack of charts in the Arctic, but it is a viable substitute for formal surveying by hydrographic offices. This is

---

[107] Department of National Defence, "Halifax HMC Ships Return from Northern Operations," *Atlantic Region News*, September 7, 2016, https://www.navy-marine.forces.gc.ca/en/news-operations/news-view.page?doc=halifax-hmc-ships-return-from-northern-operations%2Fitpjxtik.

[108] Arfeen Khaleel, "Automated Processing of Arctic Crowd-Sourced Hydrographic Data While Improving Bathymetric Accuracy and Uncertainty Assessment" (Master's thesis, The University of New Brunswick, 2019), 4, http://www.omg.unb.ca/wordpress/theses/Khaleel_Arfeen_2019-12_MScE.pdf.

[109] Ibid.

particularly the case in remote regions like the Arctic, where large areas of uncharted waters remain because any improvement in quality nautical charts reduces the risk to mariners, and thus the risk to RCN operations.

Finally, as noted, while the RCN does not have the mandate to chart Canadian waters, it does have a mandate to be able to operate in them. *Strong, Secure, Engaged* notes that the "Defence Team will enhance the mobility, reach and footprint of the Canadian Armed Forces in Canada's North to support operations, exercises, and the Canadian Armed Forces' ability to project force into the region."[110] Additionally, in the same document, the CAF indicated an intention to assist in building whole-of-government partner capabilities in the Canadian Arctic.[111] Contributing hydrographic data to the CHS crowdsourced bathymetry endeavour fulfills the requirement to be able to project force in the region by improving safe RCN access to Arctic waters, and reduces the risk to RCN operations in the region. It also fulfills the requirement to support whole-of-government partners, in this case, CHS, by building capabilities in the Canadian Arctic through the improved collection of hydrographic data. By contributing to the CHS crowdsourced bathymetry project, the RCN meets its obligations under *Strong, Secure, Engaged*, directly contributing to improvement of nautical charts in the Arctic, and mitigating existing risk to RCN operations. This contribution is a long-term investment in mitigating the risks that inadequate nautical charts have on the RCN while operating in the Canadian Arctic.

Each of these technologies can be utilized to further mitigate the physical and credibility risks to the RCN when operating in the Arctic. By improving the navigation data available to RCN vessels, the risk of a maritime grounding on uncharted dangers is reduced, and the RCN's

---

[110] Department of National Defence, *Strong, Secure, Engaged: Canada's Defence Policy*, 113.
[111] Ibid., 80.

capability to safely provide the full spectrum of naval operations in the Arctic is improved. By being able to operate safely in the Arctic, the RCN can generate additional experience involving Arctic operations. The longer a vessel can operate in the Arctic safely, and the more varied tasks that it does, the more experience the crew of that vessel gains. That experience is cumulative. Therefore, as access to modern hydrographic data improves and the scope of RCN operational capabilities expand, so will their experience. Increased quality and quantity of hydrographic data leads to expanded operations in the Arctic, which increases the institutional experience with Arctic operations, which reduces the physical risk and the risk to credibility that comes with RCN Arctic operations.

The RCN would benefit from utilizing any, or all, of these technologies while operating in the Arctic to reduce the physical and credibility risk that currently exists. RCN Arctic experience will, over time, improve as a result of continued operations in the region. This experience can be further augmented by embracing technologies that permit a full range of naval operations in a region that otherwise has severe restrictions on where a vessel can safely proceed. An RCN capability to transit anywhere in response to another vessel in danger reduces the credibility risk to RCN operations by removing the primary obstacle, the physical risk to the ship when operating in uncharted waters. By utilizing tactical and operational level technologies, the RCN can further contribute to the whole-of-government effort to better chart the Canadian Arctic and improve maritime safety.

CONCLUSION

Despite being ignored until recently by Canada for being remote, sparsely populated, and inaccessible, the implications of climate change on the Canadian Arctic have resulted in a surge of interest nationally and internationally. The fragile Arctic maritime environment is increasingly seen as a viable commercial opportunity as a less expensive transportation route, for resource exploitation, and tourism. International interest in the Canadian Arctic has prompted Canada to take practical measures to reinforce its sovereignty of the Arctic so that it can enforce appropriate regulations, maintain domestic and international recognition of its claim, and ensure that it is capable of fulfilling its obligations as the governing body of the region. The Government's reinforcement of sovereignty is in part through an improved CAF presence. In the maritime environment, this results in increased Arctic deployments for the RCN and an increased expectation that they are as capable in the Arctic as they are in the remainder of the world.

As an organization that has not had a great deal of experience in the Arctic, the RCN is exposed to the uniquely Arctic risks of physical damage to vessels and crew, and a risk to institutional credibility by not being able to respond to emergencies resulting from inadequate safety of navigation products. The RCN can leverage the technologies noted above to mitigate those significant physical and credibility risks that an increased role in a changing and dangerous environment poses to an organization that lacks experience and adequate navigation safety products.

It is unlikely that the RCN's role in the Arctic will be reduced as it was following the transfer of HMCS *Labrador* in the 1950s, or again at the end of the Cold War. Climate change has altered the Arctic environment such that it will continue to match the environment of

Canada's east and west coasts more closely. The RCN will need to continue to generate experience in Arctic operations to fulfill public and governmental expectations that it is a truly Arctic-capable navy. Lacking suitable safety of navigation products and understanding the risks to the RCN that is posed by that absence, the RCN should look to mitigate physical and credibility risks by the procurement or adaptation of technologies that can contribute to the understanding of the hydrography of the Arctic Ocean.

BIBLIOGRAPHY

A. Orthmann and A. Ziegwied. “The Force Multiplier Effect Using Autonomous Surface Vessels for Hydrographic Survey in the Arctic.” In *OCEANS 2017 - Anchorage*, 1–4, 2017.

Bartenstein, Kristin. “The ‘Arctic Exception’ in the Law of the Sea Convention: A Contribution to Safer Navigation in the Northwest Passage?” *Ocean Development & International Law* 42, no. 1–2 (February 17, 2011): 22–52.

Bell, Ryan. “Canadian Maritime Defence Diplomacy: Canada’s Ambassadors at Sea.” Master of Defence Studies, Canadian Forces College, 2020. https://www.cfc.forces.gc.ca/259/290/22/286/bell.pdf.

Boutilier, James A. *The RCN in Retrospect, 1910-1968*. Vancouver: UBC Press, 1982.

Byers, Michael, and Stewart Webb. “Titanic Blunder: Arctic/Offshore Patrol Ships on Course for Disaster.” Ottawa: Canadian Centre for Policy Alternatives, April 2013.

Canada. Crown-Indigenous Relations and Northern Affairs. *Canada’s Arctic and Northern Policy Framework*. Ottawa: Government of Canada Publications, 2019. https://www.rcaanc-cirnac.gc.ca/eng/1560523306861/1560523330587.

Canada. Department of Fisheries and Oceans. “Acquiring Hydrography Data,” January 24, 2020. https://www.dfo-mpo.gc.ca/science/hydrography-hydrographie/data-acquisition-eng.html.

———. “Arctic Charting.” Accessed November 11, 2020. http://www.charts.gc.ca/arctic-arctique/index-eng.html.

———. “Crowd-Sourced Bathymetry in the Northern Canada Area,” January 20, 2020. https://dfo-mpo.gc.ca/science/collaboration/partnership-projects/015-eng.html.

Canada. Department of National Defence. B-GJ-005-000/FP-001*, Canadian Forces Joint Publication 01: Canadian Military Doctrine*. Ottawa: DND Canada, 2009.

———. *Canada First Defence Strategy*. Ottawa: Government of Canada Publications, 2008. http://publications.gc.ca/collections/collection_2010/forces/D2-261-2008-eng.pdf.

———. “Halifax HMC Ships Return from Northern Operations.” *Atlantic Region News*. September 7, 2016. https://www.navy-marine.forces.gc.ca/en/news-operations/news-view.page?doc=halifax-hmc-ships-return-from-northern-operations%2Fitpjxtik.

———. “Harry DeWolf Class Arctic / Offshore Patrol Ship Concept of Use,” November 2015.

———. “Operation NANOOK.” Accessed November 11, 2020. https://www.canada.ca/en/department-national-defence/services/operations/military-operations/current-operations/operation-nanook.html.

———. *Quadrennial Search and Rescue Review*. Ottawa: Government of Canada Publications, 2013. http://publications.gc.ca/collections/collection_2014/snrs-nss/D92-1-2013-eng.pdf.

———. *Strong, Secure, Engaged: Canada's Defence Policy*. Ottawa: Government of Canada Publications, 2017. http://publications.gc.ca/collections/collection_2017/mdn-dnd/D2-386-2017-eng.pdf.

Canada. Environment and Climate Change Canada. *Canada's Changing Climate Report*. Ottawa: Government of Canada Publications, 2019. http://publications.gc.ca/collections/collection_2019/eccc/En4-368-2019-eng.pdf.

———. *Canadian Environmental Sustainability Indicators: Sea Ice in Canada*. Ottawa: Government of Canada Publications, 2019. http://publications.gc.ca/collections/collection_2019/eccc/En4-144-78-2019-eng.pdf.

———. *Federal Adaptation Policy Framework*. Ottawa: Government of Canada Publications, 2016. http://publications.gc.ca/collections/collection_2016/eccc/M4-133-2016-eng.pdf.

———. *Pan-Canadian Framework On Clean Growth and Climate Change: Third Annual Synthesis Report on the Status of Implementation*. Ottawa: Government of Canada Publications, 2020. http://publications.gc.ca/collections/collection_2020/eccc/En1-77-2019-eng.pdf.

Canada. Foreign Affairs and International Trade Canada. *Statement on Canada's Arctic Foreign Policy: Exercising Sovereignty and Promoting Canada's Northern Strategy Abroad*. Ottawa: Government of Canada Publications, 2010. http://publications.gc.ca/collections/collection_2017/amc-gac/FR5-111-2010-eng.pdf.

Canada. Indian and Northern Affairs. *Canada's Northern Strategy: Our North, Our Heritage, Our Future*. Ottawa: Government of Canada Publications, 2009. http://publications.gc.ca/collections/collection_2016/eccc/M4-133-2016-eng.pdf.

Canada. Natural Resources Canada. *Canada's Marine Coasts in a Changing Climate*. Ottawa: Government of Canada Publications, 2016. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2016/Coastal_Assessment_FullReport.pdf.

Canada. Office of the Auditor-General. "Report of the Commissioner of the Environment and Sustainable Development. Chapter 3, : Marine Navigation in the Canadian Arctic." Ottawa: Government of Canada Publications, 2014. http://publications.gc.ca/collections/collection_2014/bvg-oag/FA1-2-2014-1-3-eng.pdf.

Canada. Senate, Standing Committee on Fishers and Oceans. *When Every Minute Counts: Maritime Search and Rescue*. Ottawa: Government of Canada Publications, 2018. https://sencanada.ca/content/sen/committee/421/POFO/reports/MaritimeSARReport_e(forweb)_e.pdf.

Canada. Transportation Safety Board of Canada. "Grounding - Passenger Vessel Clipper Adventurer, Coronation Gulf, Nunavut, 27 August 2010." Marine Investigation Report M10H0006. Ottawa:

Government of Canada Publications, 2012. http://publications.gc.ca/collections/collection_2012/bst-tsb/TU3-7-10-0006-eng.pdf.

———. “Grounding - Tanker Nanny, Chesterfield Narrows, Nunavut, 25 October 2012.” Marine Investigation Report M12H0012. Ottawa: Government of Canada Publications, 2014. http://publications.gc.ca/collections/collection_2014/bst-tsb/TU3-7-12-0012-eng.pdf.

CBC News. “Planned Army Base, Port in North Heat up Arctic Quest.” *CBC News*, August 8, 2007. https://web.archive.org/web/20080111034225/http://www.cbc.ca/canada/north/story/2007/08/08/arctic-setup.html.

———. “Russia Says World’s Largest Nuclear Icebreaker Embarking on Arctic Voyage.” *CBC News*, September 23, 2020. https://www.cbc.ca/news/canada/north/russia-says-world-largest-nuclear-icebreaker-arctic-voyage-1.5733729.

Chénier, René, Loretta Abado, and Heather Martin. “CHS Priority Planning Tool (CPPT)—A GIS Model for Defining Hydrographic Survey and Charting Priorities.” *ISPRS International Journal of Geo-Information* 7, no. 7 (July 2018).

Chénier, René, Loretta Abado, Olivier Sabourin, and Laurent Tardif. “Northern Marine Transportation Corridors: Creation and Analysis of Northern Marine Traffic Routes in Canadian Waters.” *Transactions in GIS* 21, no. 6 (December 2017): 1085–97.

Chénier, René, Marc-André Faucher, and Ryan Ahola. “Satellite-Derived Bathymetry for Improving Canadian Hydrographic Service Charts.” *ISPRS International Journal of Geo-Information* 7, no. 8 (August 2018).

Chénier, René, Marc-André Faucher, Ryan Ahola, Yask Shelat, and Mesha Sagram. “Bathymetric Photogrammetry to Update CHS Charts: Comparing Conventional 3D Manual and Automatic Approaches.” *ISPRS International Journal of Geo-Information* 7, no. 10 (October 2018).

Das, Pallavi V. “People’s History of Climate Change.” *History Compass* 16, no. 11 (November 2018).

Dawson, Jackie, Luke Copland, Margaret Johnston, Larissa Pizzolato, Steve Howell, Ron Pelot, Laurent Etienne, Lindsay Matthews, and Jim Parsons. *Climate Change Adaptation Strategies and Policy Options for Arctic Shipping in Canada*. Ottawa: University of Ottawa, 2017.

Dawson, Jackie, Larissa Pizzolato, Stephen E L Howell, Luke Copland, and Margaret E Johnston. “Temporal and Spatial Patterns of Ship Traffic in the Canadian Arctic from 1990 to 2015.” *Arctic* 71, no. 1 (March 2018): 15–26.

Eelhart, M. W. “Charting the Future: The Need for Naval Hydrography.” Joint Command and Staff Program Course Paper, Canadian Forces College, 2013.

Epps, Sarah A. “The Feasibility of Using Inherent Optical Properties and the Apparent Optical Property Remote Sensing Reflectance to Estimate Suspended Particulate Matter, Particularly for Use in Airborne Hydrographic Surveys.” Ph.D. dissertation, The University of Southern Mississippi, 2018.

Fenn, Kirsten, and Alyssa Mosher. "Passenger Ship That Ran Aground in Nunavut Has Been Refloated, Company Says." *The Canadian Press*, August 25, 2018. https://www.cbc.ca/news/canada/north/kugaaruk-passenger-ship-refloated-arctic-1.4799050.

Geddert, Jeremy Seth. "Right of (Northwest) Passage: Toward a Responsible Canadian Arctic Sovereignty." *Canadian Journal of Political Science* 52, no. 3 (2019): 595–612.

Glanville, Luke. "The Antecedents of 'Sovereignty as Responsibility.'" *European Journal of International Relations* 17, no. 2 (May 19, 2010): 233–55.

Headland, R.K. "Transits of the Northwest Passage to End of the 2019 Navigation Season," March 17, 2020. https://www.spri.cam.ac.uk/resources/infosheets/northwestpassage.pdf.

Hodúl, Matúš, René Chénier, Marc-André Faucher, Ryan Ahola, Anders Knudby, and Stephen Bird. "Photogrammetric Bathymetry for the Canadian Arctic." *Marine Geodesy* 43, no. 1 (January 2, 2020): 23–43.

Huebert, Rob. *Canadian Arctic Sovereignty and Security in a Transforming Circumpolar World*. Book, Whole. Canadian International Council, 2009.

———. "The Melting Ice and the Transforming Arctic Ocean." *Ocean Yearbook Online* 31, no. 1 (January 1, 2017): 55–79.

Hulme, Mike. "Attributing Weather Extremes to 'Climate Change': A Review." *Progress in Physical Geography* 38, no. 4 (August 2014): 499–511.

Hydro International. "CHS Contracts for Airborne Lidar Bathymetry." *Hydro International*, September 24, 2013.

International Hydrographic Organization. "B-12 Guidance on Crowdsourced Bathymetry." International Hydrographic Organization, January 2020. https://iho.int/uploads/user/pubs/bathy/B_12_Ed2.0.3_2020.pdf.

Italy. Marine Casualties Investigation Body, Ministry of Infrastructure and Transports. "Cruise Ship Costa Concordia Investigation Report," n.d. Accessed April 14, 2021.

Jackson, Robert. "Sovereignty in World Politics: A Glance at the Conceptual and Historical Landscape." *Political Studies* 47, no. 3 (August 1, 1999): 431–56.

Jacobsen, Trudy, C. J. G. Sampford, and Ramesh Chandra Thakur. *Re-Envisioning Sovereignty: The End of Westphalia?* Burlington, VT: Ashgate, 2008.

Johannessen, Ola M., Leonid P. Bobylev, Elena V. Shalina, and Stein Sandven. *Sea Ice in the Arctic: Past, Present and Future*. Cham, Switzerland: Springer International Publishing AG, 2019.

Johnston, William, William G. P. Rawling, Richard H. Gimblett, and John MacFarlane. *The Seabound Coast : The Official History of the Royal Canadian Navy, 1867-1939, Volume I.* Toronto: Dundurn Press, 2011.

Juneau, Thomas, Philippe Lagassé, and Srdjan Vucetic. *Canadian Defence Policy in Theory and Practice*. Cham, Switzerland: Palgrave Macmillan, 2019.

Kearney, George, and John Millar. "Canadian Security and Defence: The Maritime Dimension." *Canadian Military Journal* 5, no. 3 (Autumn 2004): 63–69.

Khaleel, Arfeen. "Automated Processing of Arctic Crowd-Sourced Hydrographic Data While Improving Bathymetric Accuracy and Uncertainty Assessment." Master's thesis, The University of New Brunswick, 2019. http://www.omg.unb.ca/wordpress/theses/Khaleel_Arfeen_2019-12_MScE.pdf.

Krasner, Stephen D. "The Persistence of State Sovereignty." In *International Politics and Institutions in Time*, 39–58. OUP Oxford, 2016.

Lackenbauer, Whitney, and Adam Lajeunesse. "On Uncertain Ice: The Future of Arctic Shipping and the Northwest Passage." *The School of Public Policy Publications (SPPP)*, December 2014, 1–17.

Lajeunesse, Adam. "Canada's Arctic Offshore and Patrol Ships (AOPS): Their History and Purpose." *Marine Policy* 124 (February 1, 2021): 104323.

———. *Lock, Stock, and Icebergs: A History of Canada's Arctic Maritime Sovereignty*. Vancouver: UBC Press, 2015.

———. "The Canadian Armed Forces in the Arctic: Purpose, Capabilities, and Requirements." *The School of Public Policy Publications (SPPP)*, May 2015.

———. "Unarmed Warships: What Are the AOPS For?" Canadian Global Affairs Institute, June 2018. https://www.cgai.ca/unarmed_warships_what_are_the_aops_for.

Lajeunesse, Adam, and P. Whitney Lackenbauer. *Canadian Armed Forces Arctic Operations, 1941-2015: Lessons Learned, Lost, and Relearned*. Fredericton: The Gregg Centre for the Study of War & Society, 2017.

Larsen, Lars-Henrik, Beate Kvamstad-Lervold, Kjetil Sagerup, Victoria Gribkovskaia, Alexei Bambulyak, Rune Rautio, and Tor Einar Berg. "Technological and Environmental Challenges of Arctic Shipping-a Case Study of a Fictional Voyage in the Arctic." *Polar Research* 35, no. 1 (2016): 1–11.

Luijk, Nicolien van, Jackie Dawson, and Alison Cook. "Analysis of Heavy Fuel Oil Use by Ships Operating in Canadian Arctic Waters from 2010 to 2018." *FACETS* 5, no. 1 (January 1, 2020): 304–27.

Lund-Hansen, Lars Chresten, Ian Hawes, Morten Holtegaard Nielsen, Ingela Dahllöf, and Brian K Sorrell. "Summer Meltwater and Spring Sea Ice Primary Production, Light Climate and Nutrients in an Arctic Estuary, Kangerlussuaq, West Greenland." *Arctic, Antarctic, and Alpine Research* 50, no. 1 (January 1, 2018): S100025.

MacDonald, Adam. *The Canadian Armed Forces and the Arctic*. Conference of Defence Associations Institute, 2016.

Manda, Damian. “Development of Autonomous Surface Vessels for Hydrographic Survey Applications.” *ProQuest Dissertations and Theses*. Master’s thesis, University of New Hampshire, 2016.

Milner, Marc. *Canada’s Navy: The First Century*. 2nd ed. Toronto: University of Toronto Press, 2009.

Mugridge, David. “Is There Something Wrong With Our Bloody Ships Today?” *Canadian Military Journal* 10, no. 3 (Summer 2010): 64–66.

Notz, Dirk. “A Short History of Climate Change.” *EPJ Web of Conferences* 246 (2020).

Pastol, Yves. “Use of Airborne LIDAR Bathymetry for Coastal Hydrographic Surveying: The French Experience.” *Journal of Coastal Research*, 2011, 6–18.

Pigeau, Ross, and Carol McCann. “Re-Conceptualizing Command and Control.” *Canadian Military Journal* 3, no. 1 (Spring 2002): 53–64.

Pizzolato, Larissa, Stephen E; L Howell, Chris Derksen, Jackie Dawson, and Luke Copland. “Changing Sea Ice Conditions and Marine Transportation Activity in Canadian Arctic Waters between 1990 and 2012.” *Climatic Change* 123, no. 2 (March 2014): 161–73.

Plimer, Ian. “The Natural History of Climate Change.” *Review - Institute of Public Affairs* 61, no. 2 (August 2009): 25–27.

Severinghaus, Jeffrey P, and Edward J Brook. “Abrupt Climate Change at the End of the Last Glacial Period Inferred from Trapped Air in Polar Ice.” *Science* 286, no. 5441 (October 29, 1999): 930–34.

Shadwick, Martin. “Due North.” *Canadian Military Journal* 8, no. 1 (Spring 2007): 103–4.

Smith, Nikki. “Joint Warrior 10-1 Kicks Off with Fast-Paced Training.” Washington: Federal Information & News Dispatch, April 13, 2010.

The Economist. “The Wreck of the Costa Concordia.” *The Economist*, January 21, 2012. Canadian Business & Current Affairs Database.

Tunnicliffe, Mark. “The Naval Service of Canada and Ocean Science.” *Canadian Military Journal* 13, no. 2 (Spring 2013): 37–45.

United Nations. “Status of Paris Agreement.” *United Nations Treaty Collection*, March 19, 2021.

United Nations. Intergovernmental Panel on Climate Change. *Climate Change 2014 Synthesis Report: Summary for Policymakers*, 2014.

———. “IPCC Factsheet: What Is the IPCC?,” August 30, 2013. https://www.ipcc.ch/site/assets/uploads/2018/02/FS_what_ipcc.pdf.

———. “Reports - IPCC.” Accessed March 19, 2021. https://www.ipcc.ch/reports/.

———. *Special Report on the Impacts of Global Warming of 1.5°C: Summary for Policymakers*, 2018.

———. *Special Report on the Ocean and Cryosphere: Summary for Policymakers*, 2019.

United States. Congressional Research Service. “Weather and Climate Change: What’s the Difference?” Congressional Research Service, February 25, 2021. https://crsreports.congress.gov/product/pdf/IF/IF11446.

United States. National Oceanic and Atmospheric Administration. “Arctic Report Card 2014,” December 2014. https://arctic.noaa.gov/Portals/7/ArcticReportCard/Documents/ArcticReportCard_full_report2014.pdf.

———. “Arctic Report Card 2020,” December 2020. https://arctic.noaa.gov/Portals/7/ArcticReportCard/Documents/ArcticReportCard_full_report2020.pdf.

———. “How Long Does It Take to Produce a Nautical Chart?” Accessed November 29, 2020. https://oceanservice.noaa.gov/facts/chart_produce.html.

———. “NOAA Issues New Nautical Chart for the Arctic,” July 3, 2014. https://www.nauticalcharts.noaa.gov/updates/noaa-issues-new-nautical-chart-for-the-arctic/.

———. “What Is Lidar?” Accessed November 29, 2020. https://oceanservice.noaa.gov/facts/lidar.html.

Warburton, Moira. “Canada’s Last Fully Intact Arctic Ice Shelf Collapses.” *Reuters*, August 6, 2020. https://www.reuters.com/article/idUSKCN2523JH.

World Wildlife Fund Canada. *Arctic Shipping, Avoiding Catastrophe: Managing the Risks of More Marine Traffic in Canada’s Arctic Waters*. Book, Whole. World Wildlife Fund Canada, 2014.

Wright, R. Glenn, and Michael Baldauf. “Hydrographic Survey in Remote Regions: Using Vessels of Opportunity Equipped with 3-Dimensional Forward-Looking Sonar.” *Marine Geodesy* 39, no. 6 (November 1, 2016): 439–57.

Yip, Julianne. “Salt-Ice Worlds: An Anthropology of Sea Ice.” Ph.D. thesis, McGill University, 2019. (2457244759).

Zielinski, Xueyi Geng, Adam. “Precise Multi-beam Acoustic Bathymetry.” *Marine Geodesy* 22, no. 3 (July 1, 1999): 157–67.