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Addressing the Challenges to Search and Rescue Operations Caused by Ice Conditions in Nunavut, Canada

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ABSTRACT

Search and rescue (SAR) operations on the land, water, and ice of Nunavut are often complex and challenging due to austere environmental conditions, the strain they place on local resources, and the vast distances involved in responding with Canadian Coast Guard icebreakers or southern-based aerial assets. Using the results of a literature review, practitioner interviews, and three regional SAR roundtables conducted in November 2022 in cooperation with Nunavut Emergency Management, this paper will assess: a) how changing ice conditions in the region add to these challenges by increasing the risk of SAR incidents; b) the ways in which the ice affects response operations; and c) how ice conditions exacerbate other difficulties in the SAR system. This paper concludes with a discussion of how the Nunavut Search and Rescue (NSAR) Project aims to address these challenges, focusing on modeling and analysis approaches.

KEY WORDS: Arctic; search and rescue; climate change; ice conditions; response operations

1. INTRODUCTION

In the Canadian territory of Nunavut (NU), ice conditions constitute an important variable that can add to the complexity of search and rescue operations. Changing ice conditions have increased the risk of traveling on the territory's land, water, and ice, fueled unpredictable and expanding maritime activity, caused more incidents, and increased SAR requirements across the region. These conditions have also made the task facing government and community responders – which is often difficult due to the region's austere environmental conditions – even riskier and more challenging. The challenges posed by the ice can also exacerbate a range of other issues that affect SAR operations in the region, including severe weather, limited local resources, and the vast distances involved in responding to search and rescue incidents with Canadian Coast Guard icebreakers or southern-based aerial assets.

Using data collected through the results of a literature review on SAR in Canada's North, interviews with community, territorial, and federal government responders and planners, and four regional roundtables conducted in 2020 and 2022, this paper examines the impact of ice conditions on search and rescue operations in Nunavut. We assess how changing ice conditions in the region have increased the risk of SAR incidents, the ways in which the ice affects response operations, and how the challenges it creates can aggravate other difficulties in the SAR system. This paper is based on research being carried-out through the Nunavut Search and Rescue (NSAR) Project which will apply systems-based modelling to address these challenges and inform strategic planning, decision-making, policy development, asset deployment, and capital investment in NU.

2. THE NUNAVUT SEARCH AND RESCUE PROJECT (NSAR)

The NSAR Project is a partnership between community responders, territorial and federal practitioners, and academics with the objective of strengthening SAR prevention, preparedness, and response in the territory. With support from community SAR groups across Nunavut, the Nunavut Research Institute (Research License No. 05 018 22N-M) and the St. Francis Xavier University (File 25969), Dalhousie University (File 2022-6234), and University of Strathclyde Research Ethics Boards approved the project in the fall of 2022.

The NSAR Project is following an adapted version of the Aajiiqatigiingniq Research Model developed by the Aqqiumavvik Society based in Arviat, NU. Aajiiqatigiingniq (which means decision-making through discussion and consensus) is a fully inclusive and participatory group process that builds consensus, developing shared understandings of issues and shared commitment to solutions (Aqqiumavvik Society, n.d.). It is one of the six core guiding principles that "form the basis of an interlocking conceptual philosophy for [Inuit Qaujimajatuqangit – Inuit traditional knowledge (IQ)]" and "form a plan for the continuous application of IQ to Inuit society" (Karetak, Tester, and Tagalik 2017). The research method involves four essential components: "meaning making to achieve shared understanding of the issue; sharing real life experiences to help situate the topic; seeking innovative solutions to resolve the issue; commitment to supporting the agreed to actions to achieve resolution" (Aqqiumavvik Society, n.d.). The key to success in using this method is building relationships with and between participants – putting into action the principle of piliriqatigiingniq or coming together in an equal and collaborative relationship to work together for a common purpose (Ferrazzi et al, 2019).

Using this research approach and working with Nunavut Emergency Management and Inuit community responders, the project team organized and facilitated four search and rescue roundtables that reflected the territory's three distinct regions: the Kitikmeot (held in January 2020 and November 2022), the Qikiqtani (November 2022), and the Kivalliq (November 2022). We designed the roundtables to fulfill the first stages of the Aajiiqatigiingniq Research Model: strengthening relationships, developing shared understandings of the issues, and sharing real life experiences to better situate these issues. The roundtables brought sixty Inuit responders (the majority being SAR coordinators or team/unit leaders) and fifty representatives from territorial, federal, non-profit, and Inuit agencies and organizations together in the spirit of piliriqatigiingniq and aajiiqatigiingniq to discuss all aspects of the SAR system in the territory. Responders from every community in Nunavut save two were able to attend the roundtables and those without physical representation were able to share their perspectives via phone and email. The roundtables facilitated relationship-building and the sharing of strengths, challenges, lessons learned, best practices, and Inuit Qaujimajatuqangit for SAR prevention, preparedness, and response in Nunavut. Since the conclusion of the roundtables, we have continued to build on the collaborative relationships established through them via phone conversations, emails, and other digital engagement methods.

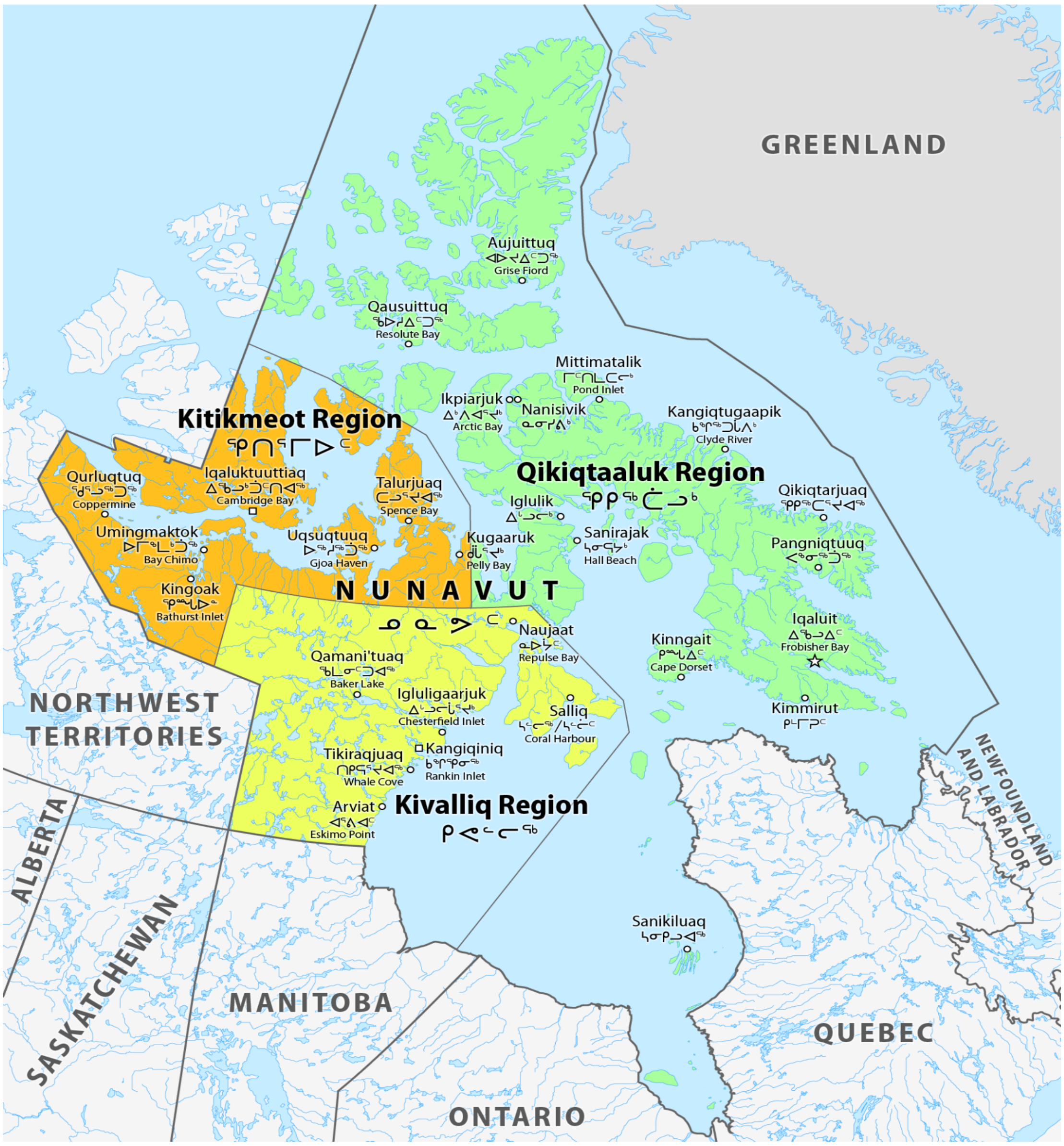

Figure 1. Map of Nunavut showing the Kivalliq, Kitikmeot, and Qikiqtani Regions and communities

3. SEARCH AND RESCUE IN NUNAVUT: ACTORS AND ORGANIZATIONS

Through Canada's National SAR Program, federal, provincial/territorial, and municipal organizations share responsibility for SAR, supported by several volunteer organizations. The Canadian Armed Forces (CAF) bear overall responsibility for the effective operation of the federal coordinated maritime and aeronautical SAR system. The CAF provides aeronautical SAR services (e.g. response to aircraft incidents; search for downed aircraft) and can assist the Canadian Coast Guard (CCG), which is responsible for the maritime SAR program component. Ground SAR (GSAR) or humanitarian cases, e.g. searches for missing hunters or boaters on inland waters, are a provincial/territorial responsibility and, in the case of Nunavut, are managed by Nunavut Emergency Management (NEM). When additional resources are required for these searches, provincial/territorial authorities can request assistance from CAF. Adding another jurisdictional layer of complexity to the SAR system is that Parks Canada is responsible for SAR in national parks, of which Nunavut has four.

The CAF's primary support for SAR includes three Joint Rescue Coordination Centres (JRCC) in Halifax, Trenton, and Victoria responsible for the planning, coordination, conduct, and control of SAR operations, five aerial squadrons specifically trained and crewed for search and rescue activities, and the Canadian Mission Control Centre. The CAF's aerial SAR assets are based in the South and often take six or more hours to reach SAR incidents in Nunavut. The CCG recently established a Marine Response Station in Rankin Inlet, which serves part of the Kivalliq region, while its icebreakers serve as secondary assets and the Iqaluit Marine Communications and Traffic Services (MCTS) Centre provides communications and alerting services. From its central office in Iqaluit or one of its two regional offices, Nunavut Emergency Management offers 24-hour support for searches, providing guidance, approving expenditures, and contracting aerial support if required.

In Nunavut, several volunteer organizations with distinct mandates and responsibilities constitute the foundation of the SAR system at the community level. Each community has an all-volunteer GSAR team, often supported by a formal SAR Committee. While team members volunteer their time and typically use their personal equipment, NEM provides funding to cover expenses such as training, fuel, lubricants, emergency supplies, food, and equipment repair (Department of Community and Government Services, n.d). Marine SAR is carried out by Canadian Coast Guard Auxiliary (CCGA) units in 11 of the territory's 25 communities. These are made up of trained local volunteers who use their own vessels or a community vessel to respond to emergencies. Another volunteer organization, the Civil Air Search and Rescue Association (CASARA) has volunteers in eight communities, including aerial spotters, trained to serve aboard military and private aircraft (CASARA, n.d.). Other community groups include the Canadian Rangers, part-time, non-commissioned CAF Reservists located in every community in Nunavut, and Inuit Guardians, Nauttiqsuqtiit (stewards), and Inuit Marine Monitors – organizations responsible for various kinds of environmental monitoring and management (Kikkert and Lackenbauer, 2019; 2021a; 2021b; 2021c).

4. ICE CONDITIONS AND RISK TO COMMUNITY ACTIVITY AND MARITIME TRANSPORTATION

In Nunavut, climate change has caused the extent, thickness, and volume of sea ice to decline, diminished ice coverage on lakes and rivers, and contributed to thawing permafrost. Community observations have reported thinner, less stable, and rougher ocean, lake, and river ice, with ice coverage developing later in the fall and melting sooner in the spring, and stronger waves and currents in the summer as waters are less impeded by ice (Auditor General of Canada, 2018; Ford et al., 2021; Barrette and Sudom, 2022).

At the NSAR Project's regional roundtables, community responders echoed previous research findings which established links between changing ice conditions and greater SAR needs in Nunavut and across Inuit Nunangat (the Inuit homeland in Canada). At the community level, the rapidly changing and increasingly unpredictable ice conditions have increased the dangers of personal travel, affecting safe access to harvesting grounds, disrupting travel between communities, and causing high SAR incident rates, injury, and deaths (Pearce et al., 2010, 2011, 2015; Durkalec et al., 2014; 2015; Clark et al., 2016a; Clark and Ford, 2017; Gearheard et al., 2017; Ford and Clark, 2019; Kikkert et al., 2020, Simonee et al., 2021; Ford et al., 2023). As highlighted by Wilson et al. (2021), Inuit are now having to navigate new, longer, and more dangerous routes on sea ice to access country food, leading to increased risk of becoming lost in unfamiliar areas. Changes to traditional sea ice routes have also led to increased fuel use, running out of gas, breaking through unexpected areas of thin ice, having to travel over rough ice and/or land resulting in snowmobiles and other equipment being lost and damaged. A case study of 202 search and rescues in Nunavut from 2013 and 2014 showed a link between sea ice, temperature, and probability of an incident (Clark et al., 2016b). Thawing permafrost is also making travel by all-terrain vehicles (ATV) more challenging in the summer months, while the early melt and late freeze up of lakes, rivers, and sea ice in the shoulder seasons (spring and fall) make travel routes more difficult and dangerous (NCCS, n.d.).

Community responders at the regional roundtables highlighted that changing ice conditions have intersected with the failure of some Nunavummiut to take sufficient fuel and equipment on the land, the loss of traditional skills and knowledge (IQ), and overreliance on technology to increase the SAR case load in their communities (echoing the previous findings of Durkalec et al., 2014; Clark et al., 2016a; Ford et al., 2019; Kikkert and Lackenbauer, 2021a). A responder from the Kitikmeot region noted that, "With climate change and bad ice, machines are getting damaged and more people are getting hurt and getting lost. Even with the most experienced people things happen" (Kikkert et al., 2020, 43-44). A SAR coordinator from the Kivalliq explained that, "Bad ice, rough ice, can make things worse. You get someone out there without skills, they don't know how to handle it. So they can get into trouble with the ice."

At the community level, sea ice reduction has also led to longer boating seasons, with boaters travelling earlier in the spring and later in the fall, risking exposure to more severe environmental conditions. As one CCG Auxiliary unit member from the Qikiqtani region explained, "People are going out on their boats earlier in the spring and later in the fall, getting into the winter because ice just isn't there anymore. Conditions are worse. You got bigger winds, bigger waves. People used to be hunting on the ice [at] this time, but now they are in boats and conditions are worse. This will lead to more cases." With less sea ice, community boats also travel further afield, with increased risks of running out of fuel or mechanical failure.

Marine traffic, including bulk carriers, fishing vessels, pleasure craft, and cruise ships, has grown significantly in Canada's Arctic waters as ice coverage decreases and summer accessibility increases – nearly tripling over the last decade and placing a growing strain on the region's SAR resources (Dawson et al., 2018, 2020; Pizzolato et al., 2014, 2016). Of particular concern are adventure cruise ships that are following diminishing ice coverage into uncharted waters, increasing the risk of a major marine accident. Roundtable participants highlighted the risks posed by the unpredictability of sea ice as it appears in new places, the choke points it can form that can trap and strand vessels, and the presence of hard multi-year ice in first-year ice, which can be difficult to detect and cause great damage in the case of collision. As vessels operate in the Arctic waters longer into the fall and the air temperature drops, icing on superstructures can create instability. Pleasure craft, often operated by inexperienced sailors with little ice experience, are also a growing concern. In August 2018, for instance, two Argentines sailing through Nunavut's Bellot Strait became trapped in the ice and started to sink, forcing them to abandon their sailboat and await rescue on an ice floe.

While changing ice conditions lead to higher risk, several roundtable participants highlighted that even when Arctic sea ice is encountered by experienced crews in areas where it is to be expected, accidents can still happen. In February 2016, the Saputi, a fishing vessel with 30 people on board, struck and was holed by a piece of ice 167 nautical miles east-northeast of Resolution Island, Nunavut, developing a severe list and requiring assistance from Canadian and Danish SAR aerial assets, while proceeding to Nuuk, Greenland. The vessel's master was experienced, the crew detected the ice the vessel struck through radar and visual observation, and they assessed it as non-threatening first-year ice. The Transportation Safety Board report on the accident concluded that "the smaller, non-threatening first-year ice pieces were likely covering a harder piece of multi-year ice or a growler." (TSB, 2017).

5. CHALLENGES TO SAR RESPONSE DUE TO ICE CONDITIONS

While the link between changing ice conditions in Nunavut, increased risk, and growing SAR requirements in the region has been well established by previous research, the NSAR Project is also exploring the ways in which ice conditions affect air, ground, and marine SAR response. The following section provides a brief overview of these factors.

Ice conditions can increase the time and risk involved in aerial search and rescue operations. Icing is perhaps the most obvious factor. While the Royal Canadian Air Force (RCAF)'s primary SAR helicopter, the CH-149 Cormorant, has a sophisticated ice protection/de-icing system, private helicopters contracted by NEM and those used by other national SAR services may not have the same de-icing capabilities. During the *Saputi* incident, for instance, the SAR helicopter dispatched from Greenland had to abort the mission due to icing (TSB, 2017).

Ice also adds to the dangers faced by RCAF SAR technicians who may have to jump into Arctic waters during a rescue. With more Nunavummiut boating earlier in the spring and later in the fall, situations may develop in which SAR Techs must jump into ice fields. In late October 2011, three SAR Techs jumped out of a Hercules airplane into ice-covered waters to rescue two Inuit hunters caught in their boat in the ice near Igloolik, Nunavut – one, Sergeant Janick Gilbert died on the mission, his body recovered in an ice field of 45 per cent slush with ice pieces up to five feet in diameter. While the investigation into Sgt. Gilbert's death could find no physical evidence he was struck by ice, the final report emphasized the ice hazard risk facing SAR Techs: "Larger pieces of ice propelled by the actions of the wind and waves may damage a raft, capsize it or eject the occupants. Once ejected from the raft, successive pieces of ice may trap the occupant under water or result in crush injuries…." (DND, 2013).

Worsening ice conditions are also creating challenges around the aerial rescue of search subjects on sea ice. In the past, helicopters and ski-equipped airframes have frequently landed on the ice to evacuate located individuals. With thinner, less predictable ice coverage, however, this procedure has become more dangerous. In 2013, two hunters were stranded on an ice floe near Arviat, Nunavut after their boat took on water. JRCC Trenton contracted a Bell 206 Jet Ranger helicopter from Custom Helicopters in Manitoba to pick them up. The helicopter landed on the ice and immediately started to sink, requiring the hunters to rescue the pilot and SAR Techs to jump on the scene (CBC News, 2013). Responders at the Kivalliq roundtable shared this story and suggested that as ice conditions continue to deteriorate, the ability of helicopters to land safely on the ice to retrieve search subjects will decline, necessitating a hoist system capability or new approaches to retrieval.

Changing ice conditions have also made the conduct of GSAR operations more challenging for community responders in Nunavut, for instance in terms of determining search areas. "I think we used to have a better idea about where to start looking, because we knew the ice. You could guess where and how far a person went. Now, if a person doesn't have a SPOT [satellite communication device], it can be much harder to know where to start searching because the ice is so different," noted one responder at the Qikiqtani roundtable. Many responders emphasized the growing need for accurate and timely information on ice conditions as they planned their SAR operations and noted how difficult this can be to acquire. Some SAR coordinators have access to local ice information from SmartICE – a university-community-government-industry partnership that combines sensor and satellite data with Inuit knowledge to generate sea-ice hazard maps (Bell et al., 2014; SmartICE, n.d.). Others rely on Facebook, SIKU (the Indigenous Knowledge Social Network), and publicly available satellite imagery to gather information on ice conditions. Although this information can be time-consuming to obtain, many coordinators do not "want to send their teams out without it."

Community responders reported that worsening ice conditions generally makes their job harder – the ice is tougher on their machines; it slows down their movements; and it can be dangerous. The story of one responder from the Kitikmeot emphasized this: "On searches, we want to get out there fast. On one search, me and my partner thought the lake ice would be good, maybe a bit thin, but good enough. So, I went over it and the back end of my machine went right in. That could have ended worse." Many SAR groups are also struggling to respond during the shoulder seasons (spring thaw and fall freeze-up), when ATVs often get stuck and require towing. Responders indicated that new training and equipment will be required as ice operations become increasingly complicated. "I think with the ice the way it is, we need new tools, new training, new tech. Dry suits. Rope rescues," concluded one responder at the Kitikmeot roundtable. This lack of training and equipment extends to recovery operations under the ice – in which local SAR groups are often involved.

Responders at every roundtable underlined the jurisdictional confusion around SAR operations centred on land-fast ice and the floe edge, particularly when this ice breaks away as an ice floe – a common cause of SAR cases in the territory. They questioned which organizations had responsibility: "NEM and local GSAR teams or is it handled by JRCC and Coast Guard?" If a snowmachine or ATV is used to reach the ice, it is a ground search and rescue. This is, however, a situation in which capabilities do not align with mandate. Often, a search on the floe edge and, more obviously, when ice breaks away from shore, would be best handled as a marine SAR case by JRCC and the Coast Guard.

On the marine side, ice conditions often complicate searches. Ice can block or slow marine responses. When the Argentine sailors abandoned their vessel in Bellot Strait, for instance, a nearby cargo ship tried to render assistance, but was blocked by the ice conditions. The reduced ice coverage has also expanded potential search areas, particularly for short-range community SAR boats looking for other Nunavummiut boaters. "The ice can get in the way of a rescue. Slow us down. It can block us. It can come in behind and block our return. It can really make things harder," explained a community responder from the Kitikmeot. With the boating season starting earlier and ending later, responders are also exposed to the harsher spring and fall environmental conditions, increasing their level of risk. Changing ice conditions also make it more difficult for the JRCCs to predict ice drift and characteristics when planning searches. Declining ice opens up new areas to expedition cruise ships, increasing the risk of a major marine accident and mass rescue operation, which would be incredibly complex and challenging in Nunavut.

While roundtable participants generally highlighted the challenges that ice conditions posed to SAR operations, some noted that they could create opportunities, as well. The ice could, for instance, provide temporary shelter to facilitate vessel evacuation (survivors may be able to shelter on ice, even if the incident is far from shore), while increased vessel traffic due to diminishing sea ice could result in more vessels of opportunity to provide aid.

6. OUTLINE OF PROPOSED SYSTEM MODELING PROCESS

While past research has highlighted many of the issues faced in northern SAR (e.g., Clark et al., 2016a; Kikkert & Lackenbauer, 2021a), there has been little focus on interdependencies between factors. Issues raised by changing ice conditions must be viewed within the wider context of Nunavut SAR as a whole, which is a multi-faceted socio-technical system comprising many varied and highly interconnected factors. Changing ice conditions exacerbate many of the challenges in Nunavut's SAR system, including training and equipment gaps, volunteer burnout, responder mental and physical health challenges, technological limitations, and coordination and jurisdictional issues. For example, many communities report problems securing sufficient volunteers for searches, often because people are hesitant to use their own personal snowmachines given the costs involved in conducting repairs and delays in receiving compensation. Climate change is causing rougher ice conditions around some of these communities, which is producing more wear and tear on machines, and is leading to even fewer volunteers. On the marine side, reduced ice coverage and the longer boating season this produces means that all-volunteer CCGA crews are on call for longer and required to stay close to their communities. For communities with small crews, this might inhibit the ability of members to harvest on the land, worsening their food insecurity and reducing their willingness to participate in SAR. A further limitation of extant research has been the focus on lived experience (historic and present) and past incidents, but future conditions may be very different and require forward planning.

In order to address the shortcomings of earlier work, the NSAR project aims to enhance SAR operations by applying modern systems-based risk analysis methods, in order to understand and analyze risks, systems deficiencies, integrated capability, and impacts of different factors systemically, and to inform strategic planning, decision-making, policy development, asset deployment, and capital investment. We also plan to adopt a scenario-based approach to elucidate unknown futures and deep uncertainties.

6.1 Model Development Process Overview

This section describes the methodology to develop a model to support decision making concerning the configuration of the SAR system in Nunavut. An essential aspect of this process is that the resulting models are grounded in community knowledge. The roundtable events provided a basis on which to develop our models. In section 6.1.1 we explain the process of representing the causal relationships between factors and outcomes in the form of a causal map, serving as a foundation for model development. In section 6.1.2 we compare five different modeling approaches we will be applying within this project to address different types of decision support. We plan to reflect back on the SAR system with relevant stakeholders/rightsholders to validate the model, which is outlined in section 6.1.3. Finally in section 6.1.4 we describe our process for engaging with the communities to reflect on medium to long-term uncertainties with the aim of developing robust strategies.

6.1.1 Causal mapping

Causal mapping was used to visualize the factors that SAR practitioners who attended the 2022 roundtables perceived as being both the biggest challenges facing northern SAR activities and the greatest strengths in the system, while also articulating the nature of the cause-effect relationships that exist amongst those factors. An initial causal map was constructed based on data from a SAR roundtable conducted in February 2020 for the Kitikmeot region of Nunavut. This causal map was then extended using data from the 2022 roundtables.

Through coding contemporaneous notes from the 2022 roundtables, a thematic analysis was conducted to determine the key themes in the data (see, e.g., Braun & Clarke, 2006). Higher-level themes were identified from the preliminary codes and extracts grouped under those themes. This was used to identify common issues across multiple roundtables as well as location-specific issues. The identified themes were used to extend and enhance the causal map from the 2020 roundtable to ensure that it reflected each major theme that emerged in the 2022 roundtables. For example, the enhanced map included more detailed articulation of decisions driving some of the key uncertainties in the system such as availability and expertise of SAR responders and effectiveness of coordination between SAR organizations. After constructing the revised map, each concept was then categorized as an uncertainty, a decision, an outcome or a constraint, based on a review of the supporting materials. Figure 1 is an extract from the extended causal map showing factors related to the impact of ice on SAR incidence and time to rescue.

Figure 2. Extract of a causal map showing factors related to the impact of ice on SAR incidence and time to rescue. Arrows indicate direction of influence between factors.

6.1.2 Systems Modelling Approaches

The causal map provides an overview of key issues that are of concern to those involved in SAR and, importantly, the interconnections between these issues. Given the dynamic, interactive nature of the socio-technical factors that are influencing the SAR outcomes, there are several other systems modeling approaches that can be used to support SAR decision-making. We discuss five approaches within this section, each of which will be grounded in the causal map described in section 6.1.1 and as such will be based on views expressed in the roundtable discussions.

Bayesian Networks (BN): This is a probabilistic graphical model, where factors and outcomes are represented by nodes, with arcs used to link nodes that have a causal relationship. A BN is similar to a causal map with the added feature that each uncertainty node is modeled with probability distributions to describe its state. These models can be used to derive the probability of outcomes such as a SAR operation given conditions such as weather, availability of assets and state of persons in distress. As such they can be used to measure the marginal contribution that such factors make toward successful outcomes and inform the anticipated impact of risk mitigation strategies. Such models are acyclic, so they do not account for feedback loops in the system. They assess outcomes at a given point in time, so they do not consider changes over time (see Norrington et al., 2008).

Causal Loop Diagrams (CLD): These provide a visual illustration of the relationship between factors and outcomes through nodes and arcs, but accommodate feedback loops. These models are helpful to identify the need for intervention on reinforcing loops where negative outcomes reduce system capacity exacerbating future outcomes (see Kosmas et al., 2022).

System Theoretic Process Analysis (STPA): Provides a visual illustration of the system using nodes together with arrows depicting flow of information and actions (control and feedback) undertaken during a SAR event. This is used to identify conditions that, when combined with worst case environmental conditions, result in undesirable outcomes. This is a qualitative approach that aims to identify requirements in order to mitigate the causes of unsafe conditions (see Charalampidou et al., 2020; Leveson, 2011).

Functional Resonance Analysis Method (FRAM): The distinctive characteristic of this qualitative approach is to consider the functions of the various aspects of the systems rather than their physical representation and structuring, and as such focuses on the dynamics between functions. Such analyses can lead to identifying cyclic dependencies and variability, and inform risk mitigation strategies (see Hollnagel, 2012; Salihoglu and Beşikçi, 2021).

Location-allocation models (LAM): These quantitative models are used to identify optimal locations of assets and services for risk problems with spatial representation, such as the location of SAR events. Such models can account for inter-dependency between assets and SAR events evaluated through multiple objectives, such as area coverage, response time, and costs (see Akbari et al., 2018; Karatas, 2021; Siljander et al. 2015).

The purpose of the modeling is to develop a coherent understanding of the SAR system. These five approaches to studying the SAR system are not incompatible but rather seek to provide complementary decision support. Two of the approaches are quantitative and three are qualitative, so differ on the demands for data as input and decision support as output.

BNs are suited for modeling the likelihood of SAR outcomes for example, the state of the casualties given factors such as ice conditions, weather, experience level of responders, availability of assets and type of incident. LAMs seek to identify the optimal location of SAR centers and assets to minimize adverse outcomes.

However, this is a socio-technical system, and changing environments result in changing behaviors. Examples of these include Inuit navigating longer and more dangerous routes on the sea ice to access food, or changes to sea ice routes leading to travel over rough ice resulting in snowmobiles being damaged. CLDs will assist in understanding how this socio-technical system is changing over time through feedback loops with behaviors responding to events thus changing the demands on the systems.

Through STPA and FRAM we seek to identify hazardous combinations of factors and support the development of risk mitigation strategies, such as changing ice conditions coinciding with the failure to take sufficient fuel combined with the loss of traditional skills and knowledge (IQ), and an overreliance on technology.

6.1.3 Model Development

Two of the five modeling approaches require quantification. This will be supported through a combination of existing secondary data on the environment and past SAR records as well as expert judgment. We will design an appropriate elicitation protocol to facilitate the expression of uncertainties as subjective probabilities by knowledgeable persons. Where possible, we will calibrate aspects of the model against existing data. For the qualitative modeling approaches, model development will be supported through engagement with experts ensuring the system is appropriately captured in the models. We will design suitable communication and evaluation mechanisms to validate and enhance all models at future roundtables. The data collected for model development and the models will be owned, controlled, and accessible by Nunavummiut involved in SAR.

6.1.4 Delivering Robust Decision Support

It is of central importance that our models provide decision support that not only represents the SAR system in its current form but is also robust to changes which could affect the functioning and/or requirements of that system in the future. Some potential changes will be on the 'micro' level, likely affecting the level of one or more specific model parameters. These micro changes may include both internal improvements to SAR operations (e.g., using unmanned aerial vehicles (UAVs) operated by Northern SAR operations for survey, situation awareness, victim location and other activities) and developments external to the SAR system (e.g., changes in marine industry protocols such as implementing a buddy system for cruise ships or introducing a stand-by vessel to respond to distress calls within designated zones). We will identify an appropriate set of test cases and perform sensitivity analysis to explore how changes to particular parameters affect model outputs.

Other changes are 'macro' in nature, reflecting large-scale trends and uncertainties that could fundamentally affect the SAR operating environment in the longer term. For example, changing ice conditions, the impact of novel technologies, demographic shifts, loss of IQ, and commercial development (mining and other industry, increased marine traffic). Here, we will use a scenario-based foresighting approach with the aim of identifying SAR configurations that are robust to alternative realizations of such key uncertainties. Our approach is based on the "Intuitive Logics" method of scenario planning, which allows the facilitated, group-based development of causally-based qualitative storylines for the unfolding of a range of alternative plausible futures for SAR operations in Nunavut. The scenario method identifies what are seen as important continuing trends and uncertainties at the PESTEL level (i.e., political, economic, social, technological, environmental, and legal/regulatory change); these will be elicited from a broad range of stakeholders/rightsholders. Interactions between elicited cross-disciplinary driving forces will also be explored. The scenario narratives developed will permutate the most important uncertainties and produce scenarios that portray very different futures – that are seen as plausible to all stakeholders/rightsholders. Models and/or strategies generated by the project can then be tested or "wind tunnelled" against the scenarios (Cairns & Wright, 2018; van der Heijden, 2004), with a view to identifying robust SAR configurations that perform well under all scenarios.

7. CONCLUSIONS

This paper has identified many challenges for SAR in the Nunavut region that result from changing ice conditions. Our work supports previous scholarship highlighting the need to continue monitoring these changes and developing better understandings of the risks they pose to communities. Moving forward, the NSAR Project will continue to work with Inuit community responders and rightholders to determine how to mitigate risks through improvements to Nunavut's SAR system. We will help illustrate how changing ice conditions can affect SAR outcomes by explicating their relationships with other relevant factors. We will develop and apply various modeling techniques and scenario-based approaches to support risk mitigation at the micro and macro level. We will also work with community responders to explore the best options for addressing the increasingly challenging environment in which they operate, such as different forms of planning, training and education, and the development of responder handbooks and standard operating procedures. Through these initiatives, the NSAR Project will answer repeated calls from Inuit organizations for innovative planning, preparation, and infrastructure development that will support Inuit in their role as the "principal players and first responders" in Arctic SAR (ITK, 2019, 7; ICC, 2019).

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