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Gap Analysis of Expected Time of Rescue and Anticipated Performance of Life Saving Appliances in the Canadian Arctic

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Introduction

Historically, the Canadian Arctic has seen little marine activity except for that of the local people who lived there, the seasonal shipping activities to support mining operations, and the annual sealift for the northern coastal communities. This was mostly due to the highly isolated and harsh environment, including significant pack ice that made much of the region inaccessible. This has changed in recent years as the reduction of sea ice in the Arctic has opened up new pathways to transit through the once near impassable environment. These new pathways have resulted in an increase in marine traffic to the region, though primarily limited to the summer months. As can be seen in Figure 1, most of the marine activity in 2017 typically consists of destination traffic rather than transit passages. Recent mining development activities have resulted in large increases in shipping activity in the Eastern Canadian Arctic in particular, which will likely continue to grow as those operations ramp up.

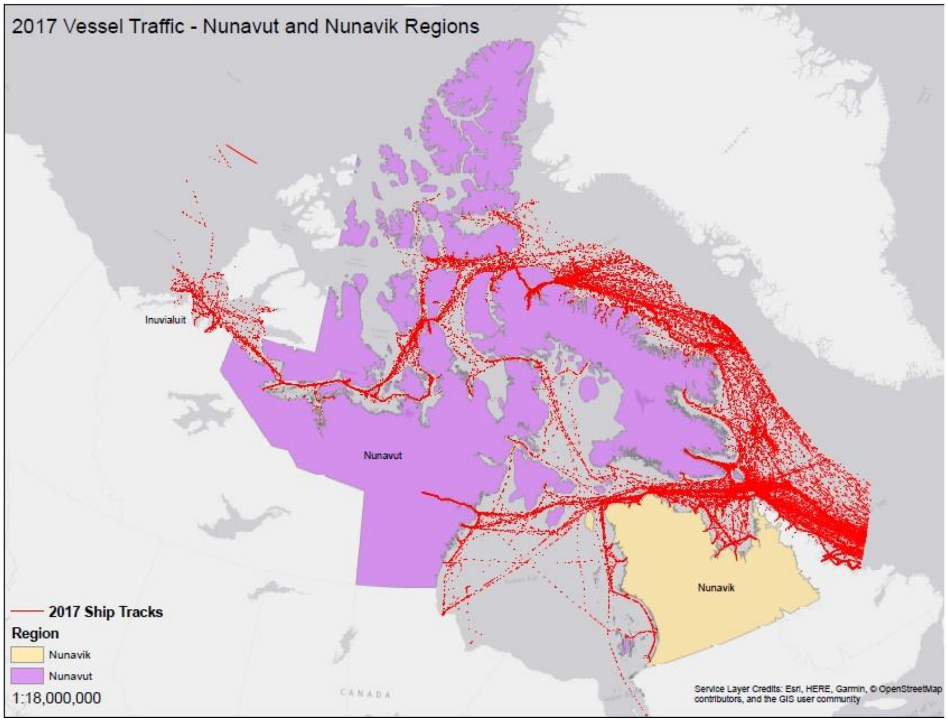

Figure 1: Vessel activity in the Canadian Arctic in 2017.

In addition to destination traffic, recent trends also show an increase in transits through the Northwest Passage as well. In 2017, a record high of 34 vessels transited the Northwest Passage (Figure 2), beating the previous record of 20 set in 2012. While most of the vessels that transited the Northwest Passage in 2017 were pleasure craft, government or research vessels, the potential of using the Northwest Passage as an ocean trade route has also regained interest in recent years, as it has the potential to significantly reduce the length of shipping routes and therefore costs.

The new pathways in the Canadian Arctic have attracted the cruise industry as people are eager to explore one of the most pristine, yet isolated, places on Earth. Interest in the polar expedition cruise industry in general has increased significantly in recent years, with 31 cruise operators currently offering expedition cruises to the Arctic and Antarctic regions, and 28 additional vessels currently on order or under construction. This increase in interest has resulted in a wide range of vessels now operating or intending to operate in Polar Regions within the past several years, including the Canadian Arctic. From 2005 to 2017, the Canadian Arctic has seen an almost four times increase in marine activity (Figure 2). From small adventure cruise ships carrying approximately 100-200 passengers or fewer, to the massive *Crystal Serenity* that transited through the Canadian Arctic in 2016 carrying ~1,600 passengers and crew members, this area is experiencing a level of marine activity and interest that has never been seen before, and that will likely grow in the years to come.

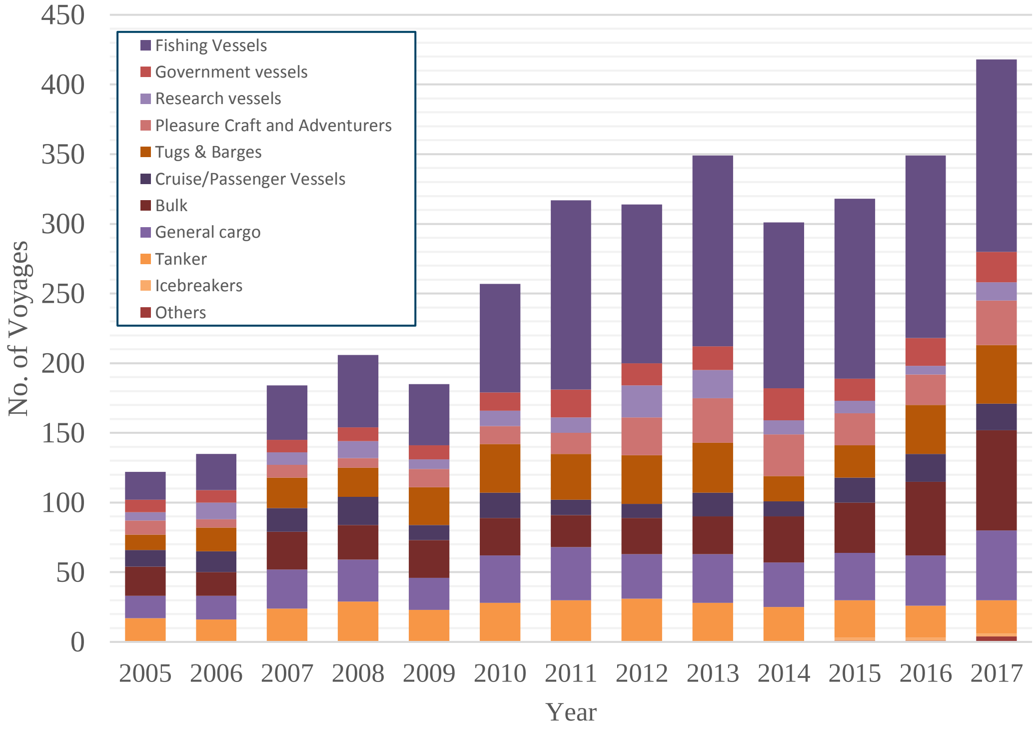

Figure 2: Frequency, and type, of marine activity in the Canadian Arctic (Frédéric, 2018).

With this increase in marine activity comes an increase in the probability of an accident occurring that may result in people having to rely on life saving appliances (LSA) in order to increase their chance of survival until they are rescued. These LSA can include immersion suits, liferafts and lifeboats, all of which are certified to a standard in order to ensure they provide a minimum level of performance.

The International Maritime Organization (IMO) LSA Code specifies levels of performance that lifesaving equipment carried on board ships must meet in order to help people survive in the event of a marine accident (IMO, 2017). However, the IMO LSA Code does not specifically deal with the full range of environmental conditions and combinations that can be experienced in Polar Regions, such as low air and water temperatures, storms, sea ice and snow, and remoteness. This was identified as a performance gap by the international community since this environment presents challenges unlike anywhere else in the world.

In response to this performance gap, IMO introduced the “International Code for Ships Operating in Polar Waters” (Polar Code) which was specifically designed to address the increased challenges of operating marine vessels in Arctic and Antarctic waters. The Polar Code requires all marine vessels operating in these areas to apply for a Polar Ship Certificate (IMO, 2015). Issuing a certificate to a vessel would ensure that an assessment has been performed that takes into account the operating conditions and hazards it may experience while traversing Arctic/Antarctic waters. This assessment would include information on identified operational limits, plans and procedures, and additional safety equipment, in the event of an accident while in Polar waters (IMO, 2015).

While the Polar Code has resulted in an increase in awareness of the risks of operating in such harsh environments, some questions remain as to whether performance gaps still exist with regards to LSA. In order to assess if these gaps exist, and if so what impact they may have on survivability, Transport Canada (TC) has requested for the National Research Council of Canada (NRC) and Aker Arctic Canada Inc. (AAC) to perform a gap analysis on the Polar Code and expected LSA performance. The goal of this gap analysis is to review the LSA aspects of the Polar Code and determine if the level of performance it specifies will be sufficient for survival in the Canadian Arctic.

Report Outline

In order to determine if the Polar Code specifies a sufficient level of performance of LSA equipment to ensure survival, and whether existing LSA are capable of meeting such requirements, this report will contain the following items:

1. Literary review of existing LSA regulations – A literary review of existing regulations (including the Polar Code) that govern LSA typically used on board Arctic-faring vessels has been conducted. This review will establish baseline performance requirements that LSA need to meet as specified in the regulations.

2. Literary review of LSA performance in Arctic conditions – A literary review of LSA performance from published studies and reports, in general Arctic-like conditions of low temperatures and high winds will be conducted. This review will provide the performance benchmarks for LSA in Arctic conditions. LSA considered in this report will include: lifeboats; liferafts; and immersion suits. The actual performance of LSA in harsh environments needs to be considered in order to determine if it is sufficient for survival.

3. Literary review of Estimated Exposure Time (EET) – The results from the work by Kennedy and colleagues “Evaluating Exposure Time until Recovery by Location” (Kennedy et al., 2013) has been used as the estimated time to rescue (ETR) for various locations in the Canadian Arctic. The length of time a person is exposed to the environment will thus ultimately be the amount of time an LSA needs to perform as expected to ensure survival.

4. Assessment of Key Environmental Parameters Influencing Survivability: For each location investigated by Kennedy et al. (2013), key environmental parameters that significantly influence survivability in a marine evacuation scenario in the Canadian Arctic were analysed. This included mean daily low temperature (from which polar service temperature can be derived) and sea ice concentraton.

5. Gap Analysis of ETR and LSA Performance – The results from the previous items will be compared against one another to determine the following outcomes:
    a. Does the Polar Code demand a sufficient level of performance from LSA to keep people safe for the ETR?
    b. Do LSA performance levels as reported in the literature meet the ETR?
    c. If LSA performance benchmark values are not sufficient to meet ETR, identify new technologies, strategies, or requirements to meet them.

LSA Regulatory Requirements in the Canadian Arctic

Overview

To help determine whether existing regulations that govern LSA performance in Arctic conditions demand a sufficient level of performance for use in the Canadian Arctic, a review of relevant regulations was performed in this report. This report focused on ships that were certified under Chapter 1 of Safety of Life at Sea (SOLAS), including commercial cargo vessels above 500 gross tons, and passenger ships (ships that carry more than twelve passengers), but excludes pleasure yachts or fishing vessels. As such, the key relevant LSA regulations considered in this review are those to which these ships would be required to comply with if they intend to operate in Canadian Arctic Waters, including the SOLAS, LSA code, the Polar Code, and the Arctic Shipping Safety and Pollution Prevention Regulations (ASSPPR).

Requirements Related to Operations in Low Temperatures

In the regulations considered, air temperature is a parameter that arises in all of them, yet there are varying approaches in how it is considered. This section provides an overview of the LSA regulatory requirements that deal with operations in low temperatures.

In general, all LSA on the abovementioned vessel types need to comply with SOLAS Chapter III (Life Saving Appliances and Arrangements) and the LSA Code. The LSA Code is a comprehensive code that outlines specifications and performance requirements and test procedures for the LSA that is required to meet Chapter III of SOLAS. While there are no specific requirements outlined in the LSA Code that apply specifically for the Canadian Arctic, there are specific design and testing requirements that consider low temperatures, which are intended to ensure functionality of the equipment when required. For example, the following requirements pertain to low temperatures:

- All SOLAS vessels need to be equipped with LSA which will not be damaged in stowage in air temperatures as low as -30°C.
- For life rafts, specified minimum temperature is required for inflation, strength (when suspended from a davit), and material flexing tests, typically down to -30°C.
- Engine starting systems for lifeboats need to be operable in temperatures down to -15°C.
- Personal LSA needs to be operational down to -15°C.

Other than the temperature related requirements described above, no other requirements are specified in the LSA Code that ensure that the equipment is functional and capable at sustaining life in low temperatures (for example, no specific requirements for maintaining a habitable temperature for survivors inside the survival craft).

The Polar Code has additional requirements for LSA carried on vessels intending to operate in polar waters in low temperatures. For example, lifeboats used on vessels in polar waters shall be of partially or totally enclosed type. This helps to ensure that occupants will be better sheltered from the wind and elements, but this alone does not guarantee protection from the cold. In addition, chapter 1.4.2 of the Polar Code states that for ships operating in low air temperature, a polar service temperature (PST) shall be specified and shall be at least 10˚C below the lowest mean daily low temperature (MDLT) for the intended area and season of operation in polar waters. Systems and equipment required by this Code (including LSA) shall be fully functional at the polar service temperature.

While the Polar Code has more stringent requirements over the LSA Code for operation in low temperatures, a number of challenges have been identified. The biggest challenge associated with the Polar Code is that there is little to no guidance to demonstrate that LSA equipment is functional down to the PST, and capable of withstanding the environmental challenges whilst providing a survivable environment for the survivors, for the expected time of rescue.

In addition, designing equipment to extremely low PST may result in requirements that are overly excessive and difficult to achieve. This is particularly the case when the PST could be -40°C or lower, where very few equipment manufacturers have equipment (including not only LSA but other deck equipment as well) that is certified for such low temperatures. Having such equipment designed and certified at such low temperatures is not only technically infeasible but financially challenging as well, due to the relatively low market demand of equipment rated at low temperatures.

Another limitation of the Polar Code is the fact that a PST is only applicable when the MDLT is below -10°C. For ships intending to operate in an area and season when the MDLT is above -10°C, a PST is not defined. In this case, there is some ambiguity as to whether any of the functional requirements apply. It seems that if a ship’s voyage is planned at a time of year and location where the MDLT is above -10°C (such as during the summer months in many of the sites considered in this report), the LSA carried on board would not be required to meet the requirements outlined in the Polar Code related to operation in low ambient air temperatures. Also, just because the MDLT is above -10°C does not mean that an evacuation scenario would never be exposed to temperatures below the MDLT. If an evacuation were to occur under either of these circumstances, and the actual temperature at the time was below freezing, survivors could potentially find themselves in a survival situation without access to adequate LSA, as was the case during the SARex 2016 exercise where both the liferaft and lifeboat were not winterized, causing people to abort the tests in a relatively short amount of time (Solberg et al., 2016). To avoid this scenario, careful consideration of the suitability of LSA used on vessels intended for these occasions is required even when the statistically derived MDLT is above -10°C.

In addition to the abovementioned requirements, all SOLAS convention ships operating in Canadian Arctic waters, apart from government vessels, need to comply with the ASSPPR. The Canadian regime has no specific provisions for LSA and arrangements unique to Canadian Arctic operations, but do specify requirements for operations in low temperatures in polar waters. According to ASSPPR, any Canadian SOLAS convention vessel that was constructed on or after January 1, 2017, and is intended to operate in low air temperature (periods when the MDLT is below -10°C) must have a winterization notation as well as meet the following LSA related requirements if it navigates in polar waters:

(1) have on board inflatable life rafts and marine evacuation systems that are designed to operate at the vessel PST, or that are protected from cold weather or fitted with means to prevent the temperature from dropping below -30ºC;

(2) have starting systems of lifeboats that are

- (i) tested to start at the vessel PST, or
- (ii) protected from the cold weather or fitted with means to prevent their temperature from dropping below -15ºC.

The abovementioned LSA requirements under ASSPPR are more or less similar to the minimum temperature requirements outlined in the Polar Code and the LSA Code, with some relaxation if the temperature can be maintained above the minimums outlined in the LSA Code. The additional lifeboat engine cold start test requirements at the PST (2i above) is a new requirement and more stringent than what is in the Polar Code (which currently has no requirements for testing at low temperatures at all), but these would likely be circumvented if lifeboats are fitted with means to prevent the temperature from dropping below the LSA Code minimums (2ii).

Under ASSPPR, vessels must also abide by the Arctic Ice Regime Shipping System (AIRSS) and the Zone Date System (ZDS) and/or IMO's Polar Operational Limit Assessment Risk Indexing System (POLARIS) to determine vessel limits in ice and permissible zones of navigation. ASSPRR also determines that ice navigators are required on Arctic-travelling vessels (with some exceptions), and requires that these navigators be qualified under the Canada Shipping Act to act as master and either have 30 days experience as master in Arctic waters or have a certificate of advanced training in Polar Waters.

Canadian flag vessels operating in Canadian polar waters also need to comply with the Canada Shipping Act, which contains regulations that demand some additional requirements for LSA on 'new' Canadian Vessels (built or having undergone a major conversion or reflagged to Canada after July 1, 1986). For example, the Life Saving Equipment Regulations state that the lifeboat cold engine starting tests needs to be performed and approved at an ambient temperature of -30°C. For comparison, the LSA Code specifies such tests need to be performed at a temperature as low as -15°C, and the Polar Code indicates that such tests need to be done at the PST or have means to prevent the temperature from reaching below -15°C. Depending on the region and season that the ship is intended to operate, the PST could be above -30°C and therefore the Canadian Life Saving Equipment Regulations appears to be more stringent that the Polar Code or LSA Code in this case.

Requirements Related to Operations in the Presence of Sea Ice

In the LSA Code, there are no requirements specified for operating in ice covered waters. All of the LSA performance testing under the LSA Code (including speed tests, drop tests, towing performance, operating of the deluge system, etc.) is done assuming ideal conditions: calm, ice free water. While all LSA need to be designed to meet these ideal conditions as prescribed by the LSA Code, it is uncertain how valid these tests are if the actual evacuation event takes place in less than ideal conditions (for example if the lifeboat/raft is dropped onto an ice floe, or needs to move away from a sinking or burning vessel in ice covered water, or tow or be towed in ice covered waters, or heavy seas, etc.). Various research activities have been performed over the years to quantify LSA performance in less than ideal conditions, and the results in many cases show that approved LSA designs are not able to tolerate actual conditions expected in the regions of interest, including those outside of the Arctic. This will be discussed in a later section of this report.

The Polar Code states that all LSA shall provide safe evacuation and be functional under the possible adverse environmental conditions during the maximum expected time of rescue. Presumably this is intended to include scenarios where pack ice is present. A key challenge is that, although the Polar Code requires different abandonment scenarios to be considered, there are no requirements for assessing the effectiveness of the chosen LSA solutions for abandonment in a variety of ice conditions. Although there are references and additional guidance material provided regarding abandonment onto ice or land, no specific guidance is provided to ensure that the LSA remains functional in scenarios where these options are not available, such as deployment in heavy pack ice. As will be discussed in the “Performance of LSA in Arctic-Like Conditions” section of this report, if sea ice exists but is not suitable for direct abandonment onto the ice, there is strong evidence that existing LSA performance will be impeded in ice conditions above approximately 7/10^{ths} concentration. In higher concentrations, there is significant concern regarding the ability of existing LSA to endure this scenario, without structural damage to the survival craft (crushing in converging ice) or with reliable operation of its machinery (engine cooling failure, or propeller/rudder damage), or the ability to move away from the hazard (evacuated vessel). It is worth noting that new international standards for the offshore oil and gas industry currently being approved (ISO/DIS 35012 - Petroleum and natural gas industries — Arctic operations — Offshore installation escape, evacuation and rescue) do explicitly specify that EER systems will be functional in all applicable Arctic conditions where the structure would be operating, and that the same level of safety will be met year-round.

Requirements Related to Operations in Remote Regions

The significance of operation in remote regions is the challenge associated with the duration of time for rescue to arrive. In the Canadian Arctic, the large geographical distances that rescue assets need to traverse are further complicated by potentially adverse weather conditions that can hamper the time for rescue assets to arrive on scene, and to carry out the recovery of survivors. As will be discussed in the “Estimated Time to Rescue” section of this report, the estimated time of rescue (ETR) of survivors is highly variable depending on the location, time of year, environmental conditions at the time, and availability of rescue assets, and in some cases, is longer than five days.

In the Polar Code, a minimum time duration needs to be adopted for the design of equipment and system that provide survival support, which shall never be less than five days. This is defined as the “maximum expected time of rescue”. It is the responsibility of the ship owner to determine the ETR to be used in the operational assessment and provide mitigating measures to address it. However, the Polar Code provides no guidance for how the ETR should be determined. This is an identified key challenge for ship owners intending to receive a Polar Ship Certificate.

Chapter 8.2.2 of the Polar Code states that “*All life-saving appliances and associated equipment shall provide safe evacuation and be functional under the possible adverse environmental conditions during the maximum expected time of rescue.”* Although additional guidance is provided for contents of personal and group survival kits (GSKs), they do not provide enough detail to ensure that the equipment supplied will be sufficient and functional to maintain survivability until rescued (for example, what is the minimum daily calorie intake requirements required to be supplied to ensure survivability to the ETR). Furthermore, the Polar Code has no minimal testing requirements to demonstrate that the proposed solution is sufficient to ensure that survival is possible to the ETR.

Relevant Regulatory Considerations Currently Under Development

Recently, changes to the regulations and interim guidelines have been proposed (and still under discussion) to improve the chances of providing a suitable survival condition in Polar Regions. For example, the work presented in IMO SSE 6-3 contains new quantitative requirements for air quality inside survival craft. This will help with providing a habitable/comfortable environment inside the survival craft, particularly if the hatches do not need to be opened to ventilate, resulting in loss of heat in the craft.

In the interim guidelines for additions to the Polar Code (IMO SSE 6-5), the working group proposed several practical tests that will help to confirm that LSA will be functional in all conditions expected during the ETR. This includes the following tests as examples:

- Tests for all LSA to prove that they are operational at the polar service temperature.
- Capacity test of survival craft, which includes a practical boarding and seating test with any additional equipment including all persons carrying their intended personal survival equipment.
- Operation of the survival craft and rescue craft in the worst ice conditions in which the ship is intended to operate.

It is expected that these types of additions to the regulations would help ensure that the LSA being used on vessels operating in polar waters are suitable for the task at hand. However, this needs to be expanded to include a wider range of operational considerations. The feedback received from practical and scientific research conducted on LSA performance are invaluable to developing regulations that ensure that people have a good chance of survival when exposed to an emergency abandonment scenario in the Canadian Arctic.

Assessment of Key Environmental Parameters Influencing Survivability

In order to begin the gap analysis, the key environmental parameters that can influence LSA performance must be quantified. Figure 3 provides the MDLT for each of the eight locations selected by Kennedy et al. (2013).

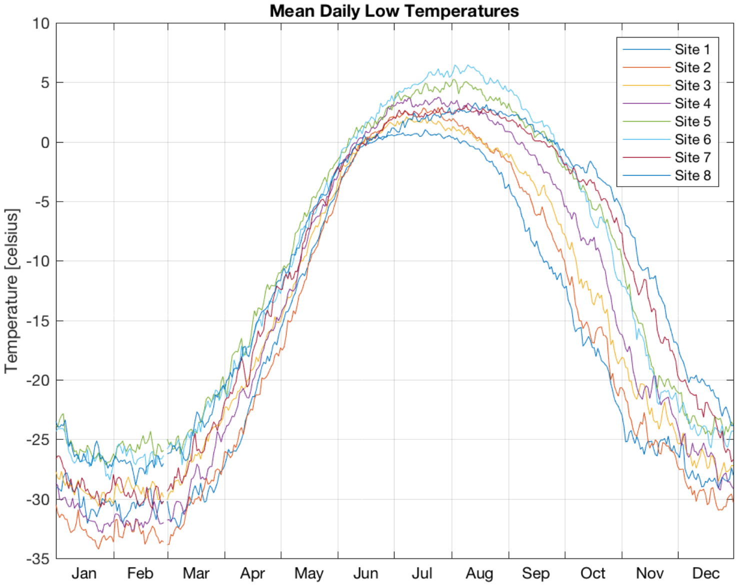

Figure 3: Mean daily low temperatures (°C) for each of the eight locations.

Table 1 provides the PST (°C) for each of the eight locations used by Kennedy et al. (2013).

Table 1: Polar Service Temperature (°C) for each of the eight locations for each month in 2017[1] (NaN = not a number).

Month	Location Polar Service Temperature (°C)							
	1	2	3	4	5	6	7	8
Jan	-43	-45	-41	-43	-38	-39	-41	-38
Feb	-43	-44	-41	-43	-37	-38	-41	-39
Mar	-43	-44	-41	-42	-37	-38	-40	-37
April	-38	-37	-33	-35	-32	-32	-32	-31
May	-26	-28	-26	-25	-22	-23	-23	-22
Jun	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Jul	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Aug	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Sep	-23	-20	NaN	NaN	NaN	NaN	NaN	NaN
Oct	-33	-32	-29	-27	-20	-22	NaN	NaN
Nov	-37	-37	-35	-34	-31	-33	-29	-27
Dec	-40	-41	-39	-40	-35	-36	-37	-34

Table 2 presents the average daily ice concentrations (X/10^{ths}) for each of the eight locations for each month of the year in 2017. Figure 4 provides the ice concentration for location one for each month of the year[2].

Table 2: Ice concentrations (X/10^{ths}) for each of the eight locations for each month in 2017.

Month	2017 Location Ice Concentration (X/10^{ths})							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Jan	10	8	8	8	8	8	8	8
Feb	10	8	8	8	8	8	10	8
Mar	8	8	8	8	10	8	10	8
Apr	10	8	8	8	8	8	10	8
May	10	8	10	8	6	8	10	8
Jun	8	8	10	3	1	6	8	8
Jul	8	6	6	0	0	0	3	6
Aug	8	4	4	0	0	0	0	0
Sep	8	6	4	0	0	0	0	0
Oct	8	6	6	0	0	1	0	0
Nov	8	6	8	8	0	8	3	8
Dec	8	6	8	8	8	8	8	8

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[1] PST only applies when the MDLT is below -10°C. For scenarios where the MDLT was above -10°C, there is no PST assigned.

[2] See Appendix B for the ice concentration graphs for the rest of the locations.

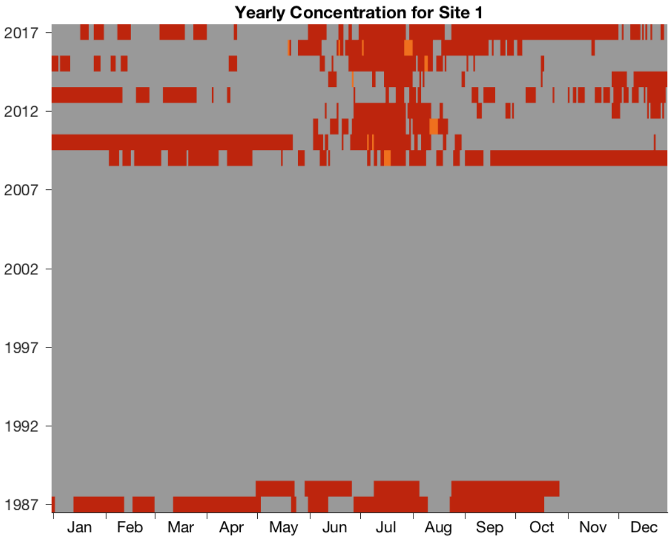

Figure 4: Yearly ice concentrations for Location 1.

As is seen in Table 2, and the figures shown in Appendix B, there are significant variations in ice concentration from site to site. At Location 1, the region is continuously covered by significant pack ice. For the other sites, the concentration is generally high during the winter months, but the ice recedes somewhat if not completely during the warmer summer months. Location 5 experiences the longest open water season, with the pack ice breakup occurring in May and June and not returning till December.

Estimated Time to Rescue

A critical piece of information needed to perform the gap analysis is the length of time a person may be exposed to the environment while they await rescue. The onus is on the ship operator to determine the maximum expected time until rescued based on the assumptions made in the Risk Assessment and Polar Water Operations Manual when applying for a Polar Ship Certificate. As discussed in the “LSA Regulatory Requirements in the Canadian Arctic” section, there is no guidance provided in the Polar Code to assist ship operators in developing a practical ETR. As a result, there may be some degree of uncertainty due to lack of a standard accepted approach, and that the reliability of the approach may likely be dependent on the experience and knowledge of the individuals performing the assessment.

The work performed by Kennedy and et al. (2013) estimated the amount of time a person may be exposed to the environment if they were stranded in the Canadian Arctic, based on the estimated time required for potential search and rescue (SAR) assets to reach the scene. For the purposes of this report, the estimated exposure time (EET)[3] calculated by Kennedy et al. (2013) will be used as the ETR. For their analysis, Kennedy et al. (2013) selected eight separate locations in the Arctic, based on marine traffic patterns, which are shown in Figure 5.

The emergency scenario designed by Kennedy et al. (2013) involved 18 people abandoning ship into two survival craft. Eighteen people were deliberately selected in order to require at least two air resources to rescue all personnel (Kennedy et al., 2013). The scenario takes place at 1:00pm in the afternoon, and it was assumed that there were no vessels or aircraft of opportunity in the area that could assist with the search and rescue effort.

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[3] Kennedy and colleagues defined exposure as the length of time from the initial communications to when all personnel are on board a rescue resource (Kennedy et al., 2013).

Figure 5: The eight locations for which estimated exposure time were calculated (Kennedy et al., 2013) .

Table 3 and Figure 6 provide the low end, and high end, ETR (EET as reported by Kennedy et al. (2013)) if both air and marine assets were tasked to a specific location. As can be seen, the ETR can vary considerably depending on the specific area considered. Kennedy and colleagues reported that many factors can influence the ETR including: weather, ice concentration, and asset availability, (Kennedy et al., 2013).

It should be noted that the work performed by Kennedy et al. (2013) assumed 18 individuals had evacuated from a sinking vessel into a lifeboat. The number of survivors can also significantly influence the ETR as well. For example, if the number of people stranded in the area is less than 15, then they may be able to be rescued by a single SAR helicopter. If the number of people is greater than that, especially if the number is in the hundreds, then marine assets will most likely be needed to rescue all the people.

A very important factor to consider is that all the results collected by Kennedy et al. (2013) were if the marine accident occurred in the month of August. Therefore: *all the following reported ETR represent a near "best case" scenario with regards to the time of year.* It is most likely that if a marine accident were to occur outside the summer months of July to September, the ETR would change, and likely increase significantly, due to worsening environmental conditions, increasing risk of storms and bad weather, shorter daylight hours, and most of all, the significant reduction in marine traffic which limits potential vessels of opportunity to assist.

Table 3: Estimated time to rescue (ETR) for air and marine resources (based on the estimated exposure times calculated by Kennedy et al. (2013)) – bold text indicates an ETR greater than five days.

		Location							
Resource Type		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Air	**Low Range (hours) (days)**	27 1.13	24 1.0	23 0.96	16 0.67	14 0.58	13 0.54	15 0.63	13 0.54
	High Range (hours) (days)	49 2.04	45 1.88	42 1.75	31 1.29	27 1.13	25 1.04	28 1.17	26 1.08
Marine	**Low Range (hours) (days)**	48 2.0	28 1.17	14 0.58	14 0.58	48 2.0	14 0.58	36 1.50	24 1.0
	High Range (hours) (days)	**237** **9.88**	**261** **10.88**	48 2.0	24 1.0	**131** **5.46**	75 3.13	**140** **5.83**	43 1.79

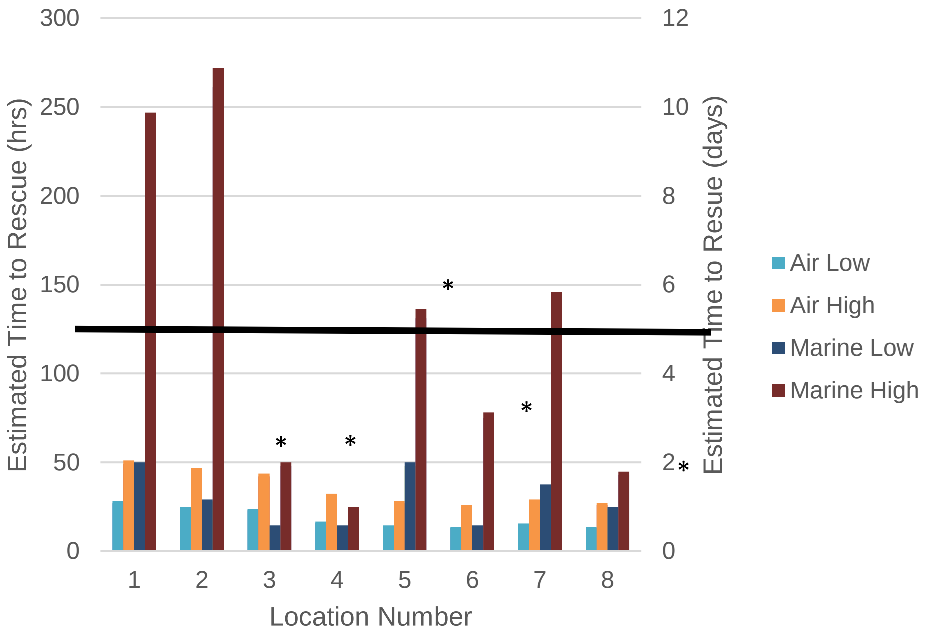
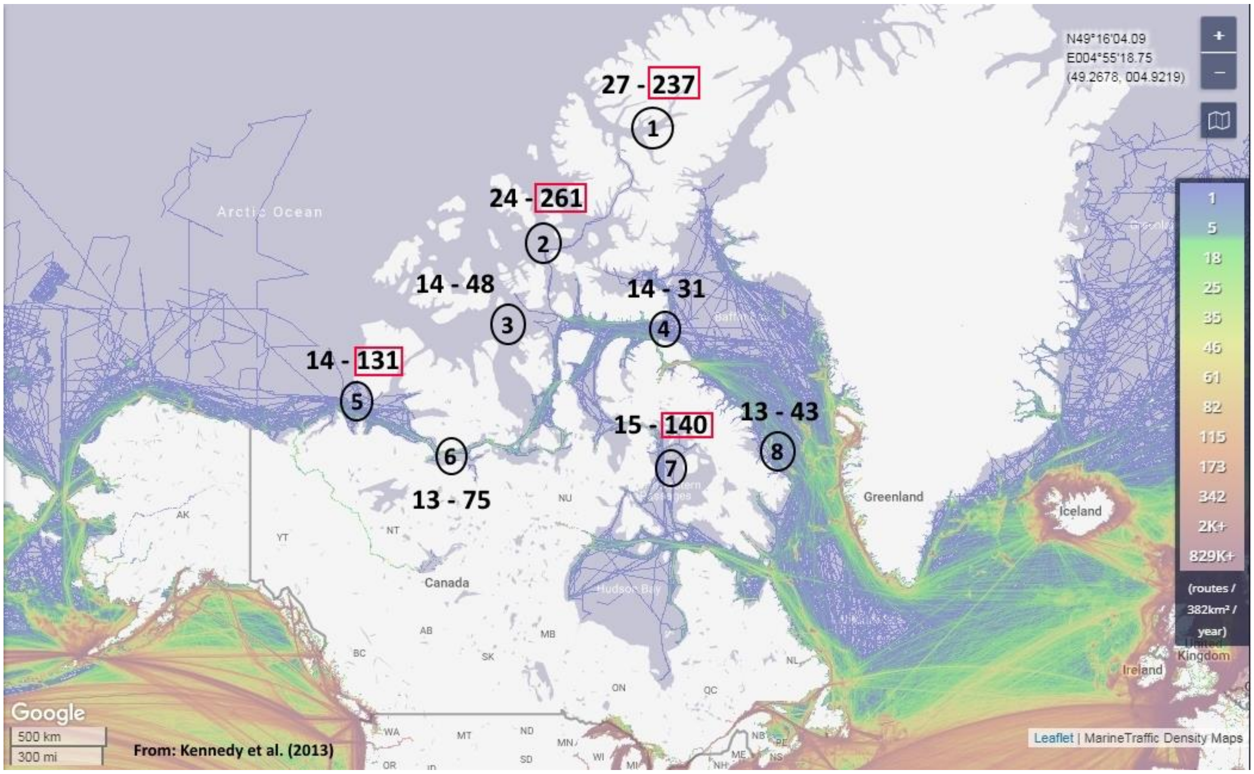


Figure 6: ETR (in hours and days) for the eight locations (black line represents the Polar Code five day minimum requirement for survivability; * = Northwest Passage location).

As can be seen in Table 3 and Figure 6, the ETR have a significant range. It can also be seen that marine resources have the highest of the high ranges; however, some locations have low range air asset values that are still greater than one day. No location is less than half a day by either resource type, which is an important consideration when it comes to the expected performance of personal protective equipment (PPE). Figure 7 provides the total range (low and high ETR values for both air and marine assets) for each of the eight locations.



From: Kennedy et al. (2013)

Figure 7: Total range of ETR (in hours) for each of the eight locations (red box denotes a time that exceeds the Polar Code minimum five day requirement).

Assuming that the 'high range' marine-based EET values were used to determine the maximum ETR for large scale evacuation scenario, the minimum 5 day requirement is sufficient for half of the sites, but insufficient for the others. Significant considerations would have to be developed in case where the ETR greatly exceeds the 5-day minimum, such as Locations 1 and 2.

Performance of LSA in Arctic-Like Conditions

Given the extreme remoteness and harsh conditions that exist in the Canadian Arctic, testing and evaluating LSA in this marine environment can be extremely challenging and impractical. As a result, many of the studies that have investigated the performance of full-scale LSA in harsh environments have been conducted in conditions that are in many cases representative of Arctic-like conditions, but in locations at a much lower latitude. As even these full scale field testing programs can be logistically and financially difficult, other studies have been conducted in controlled laboratory conditions that can recreate many elements of the harsh Arctic environment.

Lifeboat Performance in Pack Ice Conditions

One of the earliest studies that investigated the ice operational performance of a totally enclosed motor propelled survival craft (TEMPSC) style lifeboat was conducted by NRC (Simoes Ré et al., 2008). The objective of the trials was to understand the operational limitations of a conventional TEMPSC, ballasted to simulate full occupancy, in a range of ice concentrations. In this study, a 20-person TEMPSC lifeboat, with a 29 horse power (HP) engine, was deployed in pack ice conditions off the north east coast of Newfoundland, Canada. Minor modifications were made to the lifeboat to accommodate the instrumentation that was used to collect the necessary measurements during the trials, but no changes were made to alter the performance of the craft. The lifeboat was piloted by three experienced coxswains for all tests, and it was ballasted with sand bags to simulate an additional 17 people (75 kg) people on board. Ice concentration ranged from 5/10^{ths} to 7/10^{ths} for all the tests. The lifeboat crew were given instructions to head to a predetermined location in the pack ice but were allowed to take whatever route they wanted to in order to get there. Simoes Ré et al. reported that ice concentrations above 5/10^{ths} made progress difficult, or even impossible, for the lifeboat to navigate through (Simoes Ré et al., 2008). In ice concentrations at or below 5/10^{ths}, the lifeboat was able to successfully make forward progress.

Simoes Ré et al. continued their work investigating the performance of a TEMPSC lifeboat in ice in several follow-up studies. For these later studies, the same lifeboat used as in the original study (Simoes Ré et al., 2008) was modified to increase its performance. The 29 HP engine was replaced with a 54 HP model, a new propeller was installed, and a custom made nozzle was swapped with the existing one already on the lifeboat. These modifications improved the performance of the lifeboat by improving its open water top speed, and significantly increased its thrust and acceleration capabilities (Simoes Ré et al., 2011). However, even with these aftermarket modifications to increase its performance, the lifeboat still had difficulty moving through 7/10^{ths} and 9/10^{ths} ice concentrations (Simoes Ré et al., 2011).

Another study that investigated the performance of a TEMPSC lifeboat in pack ice conditions was performed (Igloliorte et al., 2008). A 40-person TEMPSC with a 20 HP engine was tested in pack ice conditions off the north east coast of Newfoundland, Canada. The tests were performed in ice concentrations that ranged from 2/10$^{\text{ths}}$ to 9.5/10$^{\text{ths}}$ with instructions given to the coxswain to move on the instructed course at best possible speed using any required manoeuvres. Igloliorte et al. (2008) found that the lifeboat was unable to move at partial broken ice concentrations of 9.5/10$^{\text{ths}}$, but said that it was able to maintain an effective speed of 1.0 $\mathrm{m \cdot s^{-1}}$ (1.94 knots) in 8/10$^{\text{ths}}$ concentration. This had a similar result to the earlier ice model testing work performed by Igloliorte et al., which found that a TEMPSC was limited in 7/10$^{\text{ths}}$ ice concentration (Igloliorte et al., 2007). However, in their report on the full scale lifeboat work, the authors make a valid observation that it was the human element that made an impact on the performance: the coxswain was able to avoid ice conditions, or be able to free the TEMPSC if it became stuck (Igloliorte et al., 2008).

Based on the work by Simoes Ré et al. (Simoes Ré et al., 2008; Simoes Ré et al., 2011), and Igloliorte et al. (Igloliorte et al., 2008), two different levels of lifeboat performance can be inferred: some are not able to make forward progress above 7/10$^{\text{ths}}$ ice concentration, while some can make some (albeit slow) forward progress in concentrations up to 8/10$^{\text{ths}}$.

The ability of a lifeboat to structurally survive heavy pack ice conditions was also tested in a full scale trials program led by BMT Fleet Technology in March 2003 (Kendrick et al., 2006). In these trials, a modern 70-person TEMPSC was deployed in pack ice in the Northumberland Strait for several days. The lifeboat was ballasted to simulate a full complement and instrumented to monitor stresses in the hull. During the trials, the dynamics of the moving ice pack resulted in the lifeboat being exposed to compressive loads on its hull. The underwater v-shape of the hull resulted in the lifeboat being lifted out of the water due to the compressive ice. While total catastrophic failure was avoided, the hull did sustain ‘moderate damage’, resulting in cracks in the hull below the waterline (Kendrick et al., 2006). It is expected that if the ice conditions were more severe, particularly thicker ice with a higher freeboard that could pinch the hull, the extent of damage would have been much higher, even catastrophic.

Lifeboat Performance in Low Ambient Temperatures

The recent SARex exercises investigated the performance of TEMPSC lifeboats with a focus on habitability in low ambient air temperatures. During the 2016 SARex trials, a 55-person lifeboat with occupants inside was deployed in approximately -9°C air temperatures with the goal being to see how long people would be able to “survive” inside the craft (Solberg et al., 2016). The authors noted that while the first few hours inside the lifeboat were tolerable, it was shortly after this time period that people had to be removed due to them meeting one of the pre-defined criteria requiring them to abort the test programme. As the test continued, people inside the lifeboat had to perform physical activity to stay warm, and the constant cold temperatures made it difficult to sleep. Air quality and low oxygen levels were continuous issues, which required frequent ventilation by opening the hatches, losing any heat that was generated inside the craft. After 24 hours, the lifeboat tests were stopped and the remaining occupants were removed. Based on the rate at which people had to be removed from the lifeboat due to meeting the pre-defined criteria, the authors generated a Kaplan-Meier Survival plot and calculated that, at the 24 hour mark, approximately only 30% of the lifeboat occupants would survive up to that point (Solberg et al., 2016).

The following year, a second SARex exercise was carried out by the same authors (Solberg et al., 2017). A 55-person TEMPSC lifeboat was once again used, but this time it was modified to increase the chance of survival in a cold climate, incorporating lessons learned from the previous year's exercise. The lifeboat had a heating and ventilation system installed, 26 insulated seats, a toilet, and a sleeping bench (Solberg et al., 2017). The air temperature was 0°C when the test started, and -9°C when it concluded approximately 30 hours later. In a marked difference compared to the 2016 SARex tests, no one was removed from the lifeboat during the 2017 tests due to meeting the test termination criteria (Solberg et al., 2017). This demonstrated that the modifications made to the lifeboat were successful in increasing the chance of survival in a TEMPSC lifeboat in harsh environments.

Similar to the findings of the SARex tests, previous work by NRC investigated the habitability of the interior of a totally enclosed lifeboat that was operating in pack ice conditions (Taber et al., 2011). When the lifeboat was operating with the hatches open, carbon monoxide (CO) and carbon dioxide (CO_2) levels remained at safe levels. However, once the hatches were closed in the lifeboat, CO and CO_2 levels quickly rose and approached maximum allowable levels within 10 minutes (Taber et al., 2011). An increase in CO_2 concentration inside of a totally enclosed lifeboat under normal operations was also reported by earlier work that found the number of occupants inside the craft affected the rate of increase (Light and Coleshaw, 1993).

At present, lifeboat manufacturers generally meet SOLAS/LSA Code compliance, and produce technical specifications to confirm this in terms of engine performance, capacity, design, and other features. The only explicit reference made to lifeboats in the LSA chapter of the Polar Code is the stipulation that they must be of totally enclosed or partially enclosed type[4], and that they must carry searchlights for continuous use. Presently, manufacturers, rather than claiming to have designed and produced Polar

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[4] There are also regulations regarding the communications capabilities of lifeboats in other chapters of the Polar Code. See chapter 10: Communications.

Code-ready lifeboats, are increasingly offering optional arctic or polar upgrade packages to enhance their existing lifeboat designs for the arctic.

The specifications of these packages are not readily available in company media. In dialogue with different manufacturers, it was determined that these packages are generally designed on a case-by-case basis, and based on the Risk Assessment, client needs, or the MDLT of the region in which they will be operating. Some possible features are improved ventilation, cabin heaters and engine heaters, and increased space per passenger, though no data on the actual performance of these enhancements in an emergency was available nor as to how they would be implemented. As was demonstrated in the SARex 2017, these “optional” upgrades appear to be a necessity for survival in Polar conditions. Thus, these features confront several issues faced by lifeboats in the Arctic; however, they must be specially requested. Per the ambiguity in the language of the Polar Code, depending upon the operating conditions and other considerations, a lifeboat can be manufactured without any of these enhancements and still be considered compliant with the Polar Code.

Certain trends among manufacturers indicate possible improvements in lifeboat performance in the Arctic region. For example, the Polar Code specifies that lifeboats must either be totally enclosed lifeboats (TELBs) or partially enclosed lifeboats; overwhelmingly, manufacturers are producing TELBs, which offer significantly more shelter at sea in the Arctic than their partially enclosed counterparts. Some Arctic cruise ships, however, still outfit their ships with partially enclosed lifeboats. As well, several manufacturers have developed lifeboats with more room per occupant, some allowing for an average mass of up to 105 kg per occupant rather than the LSA Code required mass of 75 kg per person for passenger vessels and 82.5 kg per person for cargo vessels[5]. Since space was deemed a major concern in both SARex 2016 and SARex 2017, increasing space is a significant improvement to increase occupant comfort, which will help them endure while they await rescue.

Liferaft Performance in Pack Ice Conditions

Unlike lifeboats, there exists a paucity of information on the engineering performance of liferafts in ice covered waters. It is likely that a liferaft made of rubberized fabric would be easily crushed in converging pack ice conditions, and therefore not be able to maintain a habitable environment for survivors in this condition. Also, due to lack of data, it is not known whether life rafts would be able to withstand ice abrasion in pack ice. Given the lack of actual field data on engineering performance, it is therefore difficult to believe that, from a strictly engineering based performance perspective, life rafts would be suitable for use in ice covered waters. Presently, it appears no large scale tests have

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[5] LSA Code 4.4.2.2.1

been conducted by manufacturers regarding life raft performance in ice. The LSA Code specifies that a raft must be able to withstand exposure at sea for 30 days in any conditions, but this has not been tested for polar waters, which are susceptible to extreme temperatures, ice, and polar lows: short but extreme storms

Liferaft Performance in Low Ambient Temperatures

Life rafts are not explicitly referred to in the chapter governing LSA in the Polar Code, though they are discussed in this chapter under the term “survival crafts”, and it is specified that they must function at the PST and in all environments in which they are expected to be used. As a result of this requirement, several life raft manufacturers have developed life rafts that are more suited to operations at low ambient temperatures. These rafts are generally described as such due to their specialized launching apparatuses, which have been designed to allow for raft inflation at low temperatures such as those found throughout the Arctic region. This is achieved through heating blankets or pads to keep the uninflated raft ready to deploy, or through nitrogen inflation, and manufacturers are claiming quick and reliable inflation at temperatures from -50°C to -70°C.

The thermal protection offered by liferafts was investigated in controlled laboratory conditions (Mak et al., 2009). Volunteers spent eight hours in a 16-person liferaft floating in the NRC Ice Tank that had 5°C water and 5°C air. Various physiological measurements were made on the participants in order to calculate their predicted survival times using thermoregulatory modelling computer software. Mak et al. (2009) reported the predicted survival times [6] for three conditions:

- Optimistic: The liferaft is fully occupied, dry, and the floor is insulated.
- Intermediate: The liferaft is only 50% occupied, the occupants are wet, and the floor is insulated.
- Pessimistic: The liferaft is only 10% occupied, the occupants are wet, and the floor is uninsulated.

Mak and colleagues found that under optimistic conditions, the predicted survival times of the liferaft occupants exceeded 36 hours[7] down to air temperatures as low as -20°C (Mak et al., 2009). Under the intermediate conditions, it is only when the air temperature drops below -5°C do predicted survival times drop below 36 hours, with the lowest value being ~ 13 hours in -20°C air. In the pessimistic conditions, predicted survival time drops below 36 hours at ~ -3°C, with the lowest value being ~ 10 hours in -20°C air.

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[6] Survival time is defined by Mak and colleagues as the length of time required for a person’s deep body temperature to drop below 28°C

[7] Thirty-six hours is the maximum predicted survival time estimate. After 36 hours, factors other than hypothermia will most likely result in death (Keefe and Tikuisis, 2008).

An incidental finding from the work by Mak et al. (2009) was that CO_2 levels inside the liferaft rose above 5,000 ppm in an under an hour when the craft had its hatches closed and no wind blowing over it. In a subsequent test, the speed of the wind blowing over the liferaft was deemed sufficient to keep CO_2 levels at safe levels for the three individuals in the 16-person liferaft (Mak et al., 2009).

The predicted survival time values reported by Mak et al. (2009) were calculated from physiological data collected under controlled laboratory conditions in relatively “warm” conditions compared to temperatures found in Arctic regions. Later work in the SARex exercises (Solberg et al., 2016; Solberg et al., 2017) investigated the habitability of liferafts in more Arctic like conditions.

The authors of the SARex 2016 report had 19 volunteers enter a 25-person liferaft and attempt to stay in it for as long as possible in -9°C air (Solberg et al., 2016). Some of the volunteers wore a variety of survival suits while inside the liferaft, while others wore vests with a thermal protective aid. After only 19 hours, none of the volunteers remained in the liferaft, having been removed because they met one of the test termination criteria. An important point to note is that the liferaft used in the SARex 2016 did not have an inflatable floor; therefore, much of the heat loss was a result of contact with the cold floor of the liferaft. However, even the occupants who were wearing PPE rated down to well below the ambient temperatures at the time of the trials were not able to stay for any longer than 19 hours, suggesting that relying on existing PPE designed for low temperatures alone is insufficient.

In the follow up SARex 2017 exercises, the 25-person liferaft used was equipped with an inflatable floor. In contrast to the 2016 trials, in the SARex 2017 tests, the volunteers were able to stay inside the liferaft for 23-30 hours, which demonstrates the importance of having an inflatable floor inside a liferaft to provide insulation (Solberg et al., 2017). The authors do note, however, that survival for five days in polar conditions depending on the equipment utilized in the SARex 2017 tests would still be extremely challenging (Solberg et al., 2017).

Performance of Immersion Suits in Canadian Arctic Waters

The vast majority of immersion suit studies have been performed in controlled, laboratory conditions (Hayes et al., 1985; Tipton, 1991; Ducharme and Brooks, 1998; Faerevik et al., 2010; Power et al., 2015) or in sheltered harbours (Steinman et al., 1987) Therefore it is hard to extrapolate what immersion suit performance would be in Arctic-like conditions. Previous work (Power et al., 2016) has suggested a level of performance that, theoretically, may allow a person to survive in the Arctic until rescue arrives. Based on the calculations by Power et al. (2016), a person who is wearing an immersion ensemble (immersion suit plus the clothing worn underneath) with an immersed clo value of 2.64 in calm water should, in theory, be able to remain in thermal balance[8] while also accounting for the ~43% decrease in thermal insulation due to wind, waves, and water leakage. While the IMO LSA code does not specify an immersed clo value when certifying immersion suits using human volunteers to test the suit, the estimated 2.64 immersed clo value (as measured by humans and calculated using the formulae from Power et al. (2016)) is extremely high and may be difficult to achieve with many commercially available immersion suits. In Canada, the thermal insulation provided by immersion ensembles can be measured using a thermal manikin, with the minimum immersed clo value required being 0.75 clo (CGSB, 2005). However, thermal manikins do not measure immersed clo in the same fashion as humans: thus, a correction factor needs to be applied. Previous work by Power et al. (Power et al., 2015) developed such correction factors to equate the clo value as measured by thermal manikins to that of a human. Using these correction factors, the proposed 2.64 immersed clo value as measured by humans would equal 2.16 immersed clo as measured by a thermal manikin.

Based on these calculations, an immersion ensemble would need to have an immersed clo value (as measured by a thermal manikin) almost three times higher than the minimum required 0.75 clo in order for a human to theoretically remain in thermal balance in 0°C water, with wind, waves, and water leakage under the suit. This remains a strictly theoretical hypothesis, as the practicality of surviving for an extended period of time (more than six hours) in an immersion suit in Arctic waters is extremely dubious. The design goal of all immersion suits is to delay the onset of hypothermia for at least six hours (CGSB, 2005; IMO, 2017).

Performance of Group Survival Kits

In the event of a large number of people being stranded in the Arctic following a marine or air accident, the Royal Canadian Air Force (RCAF) will deploy GSKs to the area, along with trained military personnel, from fixed wing aircraft. While awaiting rescue, the GSKs are designed to help increase the chance of survival for the stranded people by providing supplies such as heaters, tents, warm clothing, rations, and water. These GSKs are designed to provide a specific level of support for a set number of people in a given environment (RCAF person communication).

The ambient environmental conditions can also affect the level of protection offered by the clothing provided in the GSK. Wind and wetting of the clothing can have a significant impact on the level of thermal protection provided by the equipment. Previous work by Power and Monk measured the thermal insulation provided by a variety of clothing ensembles, and used these values to calculate predicted survival time for 50th

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[8] Thermal balance being defined as heat lost to the external environment being equivalent to the heat being generated by the thermoregulatory system.

percentile 60 – 70 year old females[9] in -15°C air (Power and Monk, 2012). The results are given in Figure 8.

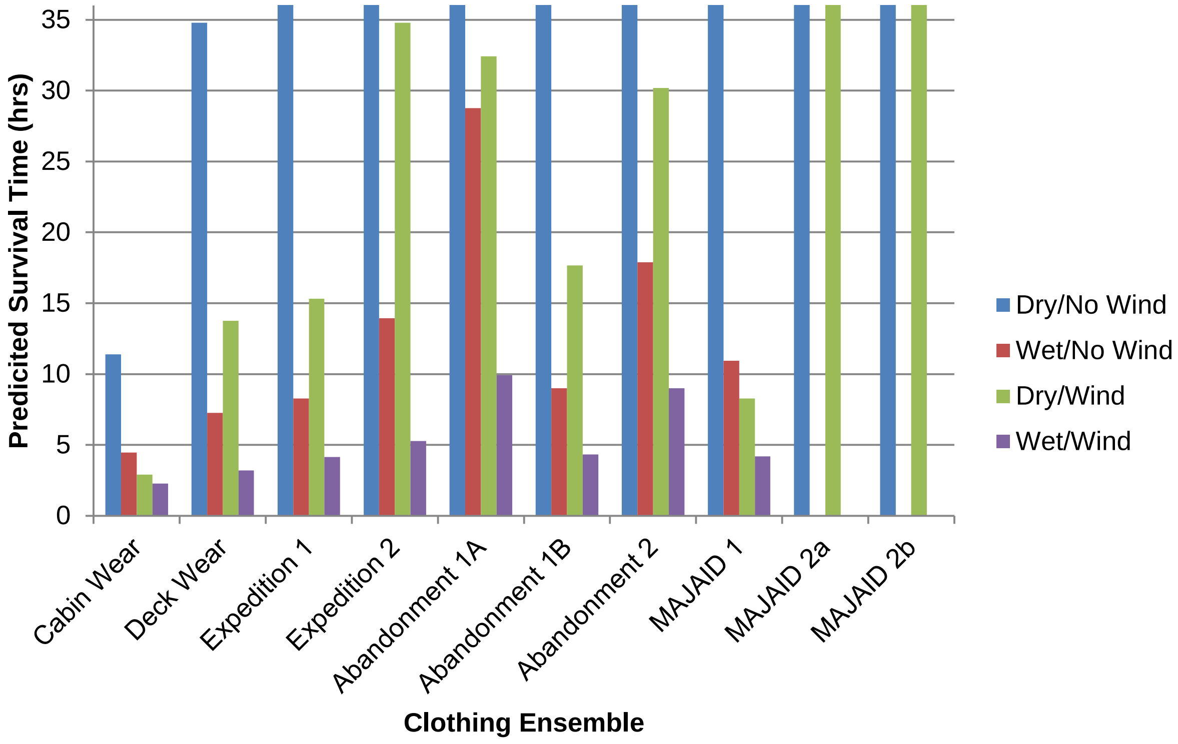

Figure 8: Predicted survival times (hours) for 50th percentile 60 – 70 year old females for all clothing ensembles10 in varying conditions in -15°C air (Power and Monk, 2012).

The results from the work by Power and Monk suggest that only under the most ideal conditions (no wind and completely dry) do the clothing ensembles provide a sufficient level of thermal protection to delay the onset of hypothermia in -15°C air (Power and Monk, 2012). This would mean that not only will the right kind of clothing be required for survival in the Arctic, but it would also require the proper knowledge and training to ensure it can perform to a sufficient level to delay the onset of hypothermia. For example, it would not be sufficient to simply wear the clothing in the open; the majority of the ensembles cannot be exposed to wind without significant decrease in insulation, meaning that a wind break or temporary shelter, such as a liferaft, would need to be used.

The third SARex exercise also investigated the performance of different clothing ensembles being worn by people who were simulating a cruise ship abandonment who made it to shore and are awaiting rescue (Solberg and Gudmestad, 2018). Forty-one

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[9] 60-70 year old females were considered the "worst case" scenario, from a physiological perspective, with regards to remaining in thermal balance and preventing the onset of hypothermia. All other demographics would have a longer predicted survival time.50th percentile refers to 50% of the group surviving.

[10] See Appendix A for clothing descriptions.

people were placed on a beach wearing a variety of clothing ensembles based on the Polar Code recommendations for personal survival kits (PSK) and GSKs. The air temperature ranged from 3°C during the day, to -3°C at night. In the first 12 hours of the test, almost 20% of the 41 participants had to be removed from the exercise mainly due to the development of hypothermia (Solberg and Gudmestad, 2018). The remaining individuals were able to survive for the remainder of the exercise, but this required many of them to perform bouts of high physical activity to increase the metabolic heat output to compensate for the heat loss. As the SARex authors noted: the participants knew that the “short” duration of the exercise was only 48 hours so they performed these sessions of high physical activity to keep warm (Solberg and Gudmestad, 2018); it would be difficult to extrapolate if people could maintain this level of effort for up to five days.

Gap Analysis of Estimated Exposure Time and Life Saving Appliance Performance

With the LSA performance data, ETR, and environmental conditions identified for each of the eight locations of interest, it is possible to estimate existing LSA performance in selected locations in the Canadian Arctic. Existing LSA performance can then be compared to required LSA performance. The results of this analysis and identified performance gaps is summarized in this section.

Lifeboat and Liferaft Ice Operational Performance

Based on the previous work by Simoes Ré et al. (2008) and Igloliorte et al. (2008), the engineering performance of lifeboats can be approximated for each of the eight locations. Engineering performance in this context can be defined as the ability for the lifeboat to make forward progress without too much difficulty, although movement will be below the IMO LSA code specified speed of 6 knots. Simoes Ré et al. (2008) reported that the lifeboat was unable to make progress in ice concentrations of about 7-8/10^{ths} and higher, while Igloliorte et al. (2008) indicated that their lifeboat was able to make some (albeit slow) progress through ice. Therefore, it can be assumed that lifeboat performance is generally restricted in concentrations around 7-8/10$^{ths.}$ Figure 9 provides an indication of a lifeboat to make forward progress in each of the eight locations for each month of the year.

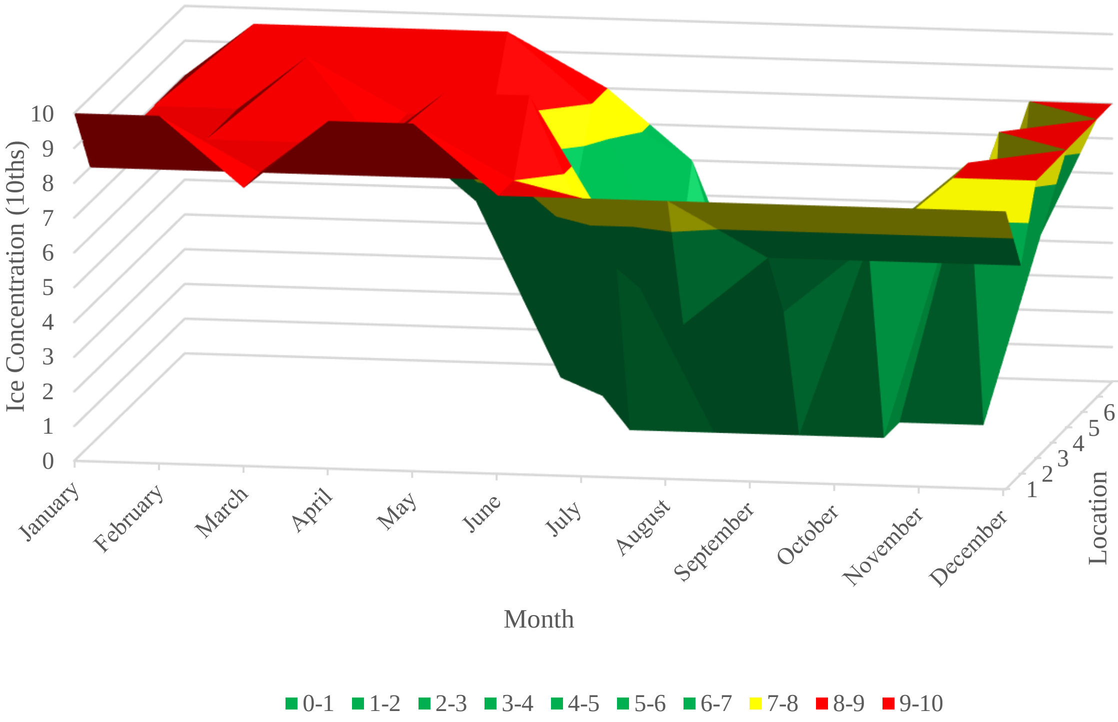

Figure 9: Lifeboat engineering performance in varying ice concentrations for each of the eight locations for each month of the year. Legend: green = lifeboat should be able to make forward progress; yellow = lifeboat forward progress possibly restricted; red = no forward progress).

As shown in Figure 9 (with the exception of Location 3 which sees significant ice concentration year-round) there is a significant period of the year (typically from November/December till June/July) where the concentration is above 8/10^{ths}. At present, there is no shipping activity during these time periods, with the possible exception of Location 8. In these ice concentrations, a conventional lifeboat is not expected to be able to make any forward progress at all. Conversely, with the exception of Location 1, there is a significant period of time where the ice concentration levels are sufficiently low that should allow a lifeboat to make forward progress. In the shoulder seasons, a lifeboat may or may not be able to make progress. Therefore, it is extremely important for marine vessels to not only be cognizant of the location they are operating in, but the time of year as well if they wish to be able to successfully transit away from a stricken ship in a lifeboat.

Based on research available to date, not only is a lifeboat's forward progress highly restricted in high ice concentrations, they are also susceptible to structural damage and mechanical failure, particularly in pressured ice conditions or when interacting with floes whilst attempting to make forward progress. As examples, the hull could be punctured during ice impact, or ice could damage the propeller or rudder, or the craft's seawater intake could become clogged with ice. These scenarios could result in the loss of functionality or even complete loss of the survival craft. Therefore, in addition to the ability to make forward progress in ice, multiple factors are at play which influence operational performance of survival craft and its ability to provide a habitable environment until rescued. These additional factors and the ability of survival craft to survive such scenarios should be investigated further.

While the authors are unaware of any full scale testing references of liferaft performance in pack ice, it is likely that liferafts would fare even worse than the lifeboats in pack ice, especially in converging ice conditions. Therefore, it is expected that current off the shelf LSA is not able to maintain a survivable environment for survivors in ice concentrations above approximately 8/10^{ths} for lifeboats, and likely lower for liferafts. The only exception may be in scenarios where floes are sufficiently large and thick to support the weight of survivors and their equipment. In this case, it may be possible to pull the liferaft out of the water and onto the floe, and use the raft as a shelter. It is expected that each site would have such sufficiently large thick floes for most of the winter months, and possibly during early part of the spring season when the ice is breaking up.

Some research has been done to develop evacuation craft that are designed to operate in a wide range of environmental conditions expected in Polar Waters, even significant pack ice, including the Ice Strengthened Lifeboat (Browne et al., 2008; Martin, 2017), and Arktos (Seligman et al., 2008) evacuation systems. Each have used different design philosophies to develop a system that is suitable in the wide range of environmental conditions expected in polar waters, typically at the expense of reduced number of survivors it can carry and increased size and cost when compared to conventional survival craft.

Lifeboat and Liferaft Habitability

Based on the results from the SARex 2016 exercise (Solberg et al., 2016) that gave the predicted survivability of individuals inside a liferaft and lifeboat , environmental data and expected time to rescue using air assets for each of the eight locations, it is possible to estimate whether it is possible for people to survive inside these LSA until rescue arrives. These results for possibly surviving in a liferaft are presented in Figure 10. The ambient air temperature during the SARex 2016 exercises ranged from -10°C – 0°C. For the liferaft comparisons, if the PST in a specific location was within 10°C of the SARex 2016 air temperature, then it was assumed that the survival rate would be near equivalent as calculating the decrease in predicted survival time due to colder temperatures is beyond the scope of this report.

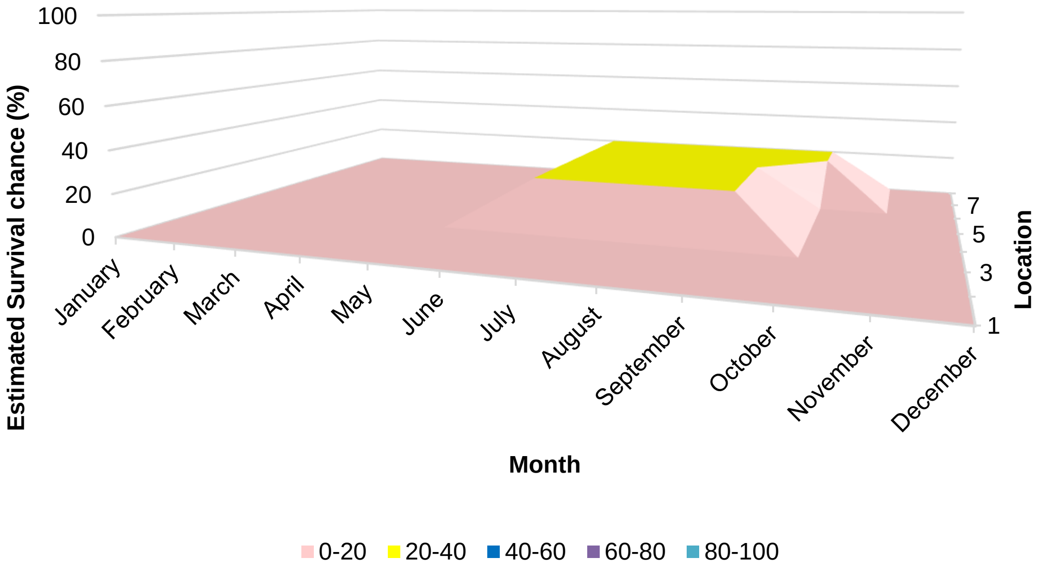

Figure 10: Survival chance for a non-winterized liferaft for each of the eight locations for each month in the Canadian Arctic.

These results suggest that for the majority of the locations for most of the year, a person would not be able to survive in a liferaft that does not have an insulated floor until air assets were able to reach them. Even during the warmer, summer months (Figure 10), it is estimated only 20% of the people may possibly survive until air assets arrived at their location, based on the findings from the SARex 2016 trials. This would indicate that a liferaft with an inflated floor is essential for having even the smallest possibility of surviving in the Arctic until rescue, as the liferaft occupants in the SARex 2017 trials were able to stay inside the liferaft with the floor inflated for significantly longer than the previous tests (Solberg et al., 2017).

While the Polar Code does not specifically require LSA to be winterized, it does state that equipment should support survival until the maximum expected time of rescue (IMO, 2015). Depending on where, and when, a vessel operates some LSA may be able to provide sufficient protection until rescue arrives without needing to be completely winterized. The onus remains on the operator to perform the proper risk assessment to determine what the conditions are in the area of operation, the actual performance of the LSA they are using (e.g. can their liferafts actually provide sufficient thermal protection, or do they need an inflatable floor?), and the ETR if an accident were to occur.

For the lifeboat comparisons, it was assumed that, regardless of the exterior temperature, the microclimate inside the craft would not be affected. It is also beyond the scope of this study to try to estimate the interior temperature of a lifeboat for a given external environment. As a result, the chance for surviving inside a non-winterized lifeboat was assumed to be the same for each location regardless of the ambient environmental temperatures. Figure 11 gives the estimated survival chance inside a non-winterized lifeboat (based on the results from SARex 2016) for each of the eight locations until rescued. These are conservative estimates and would most likely decrease as the ambient air temperature became lower than those measured during the SARex 2016 exercises.

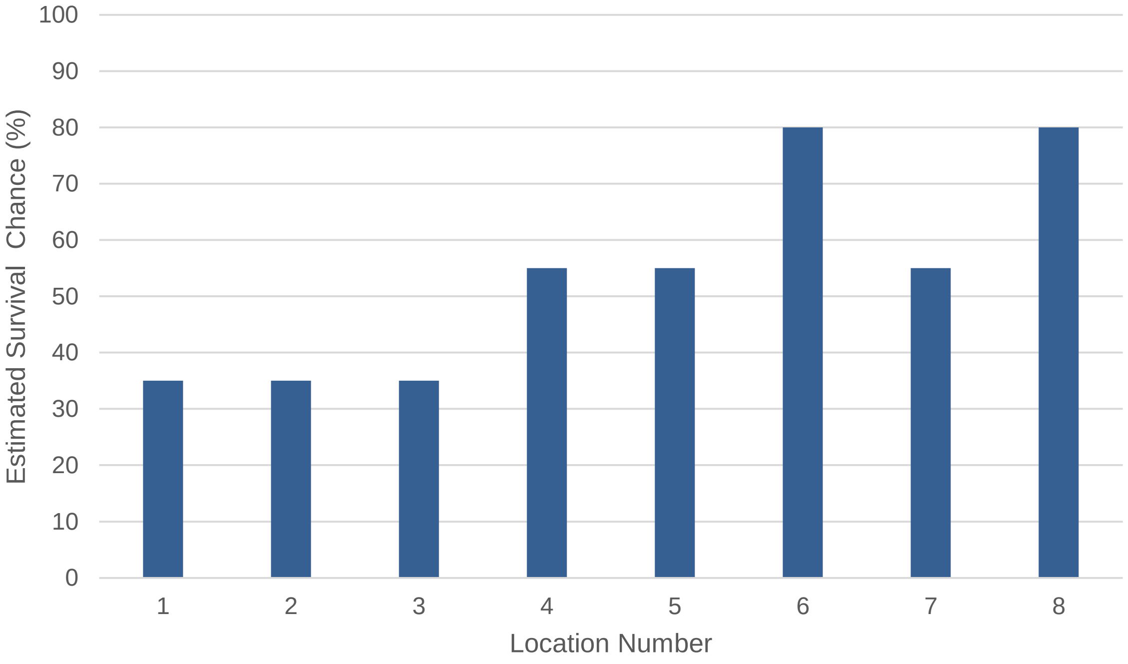

Figure 11: Estimated survival chance (%) in a non-winterized lifeboat for each of the eight locations based on ETR.

Based on the lessons learned from SARex 2016, surviving until rescue arrives inside a lifeboat that does not have any special winterization considerations would be extremely low for the majority of locations when marine vessels are operating in them. Only 35% of the lifeboat occupants are estimated to survive until rescue arrives in locations 1-3; 55% for locations 4, 5 and 7; and 80% for locations 6 and 8. Compared to the SARex 2016 exercises (Solberg et al., 2016), the SARex 2017 (Solberg et al., 2017) lifeboat occupants were able to stay inside the craft for significantly longer due to the winterization upgrades which included a heater. Based on these estimates, it is strongly recommended that all lifeboats operating in the Canadian Arctic be winterized to include a supplementary heat source.

Previous work by Power (2018) predicted an internal air temperature inside of a survival craft to remain in a thermal balance for a given clo value. The lower the air temperature inside of a survival craft, the higher the clo value required to remain in thermal balance (Power, 2018). Given the predicted high clo value of the clothing ensembles required to remain in thermal balance at lower temperatures, it is recommended that the minimum interior air temperature of a survival craft should be 10°C, with the occupants wearing an appropriate level of PPE.

It must be noted that these assessments of survivability are based on a “best case” scenario with regards to ETR. As previously stated: the times that Kennedy et al. (Kennedy et al., 2013) estimated for exposure time are for the month of August; one of the warmest months for the Arctic. It can therefore be assumed that actual rescue times may in fact be higher than the values used for the estimated survival chance in Figures 10 and 11. Additionally, the ETR values used in Figures 10 and 11 are the “low” values for an air rescue; the best case scenario with regards to having a SAR asset on scene. As reported in Table 1, the “high” values for an air rescue can possibly be almost double the “low” value. Even during the month of August, ETR may be higher than what was used in Figures 10 and 11, possibly resulting in even fewer people being able to survive.

Along with the temperature inside of the lifeboat and liferaft, air quality also needs to be considered as previous works (Light and Coleshaw, 1993; Mak et al., 2009; Taber et al., 2011) have shown that CO (motorized lifeboats only) and CO_2 levels can rise quickly inside these survival craft. While a static ventilation rate of 5.0 $m^3 \cdot hr^{-1}$ per person has been suggested for totally enclosed lifeboats (IMO, 2017) to keep CO_2 levels below 5,000 ppm, it has also been suggested that sensors be used to monitor the gas levels inside survival craft to ensure occupant safety (Power, 2018).

Immersion Suits

As mentioned in the previous section, it is highly unlikely that an immersed individual would be able to survive in an immersion suit in Arctic waters even assuming the lowest possible rescue times. The theoretical level of insulation required by an immersion ensemble to remain in thermal balance in such extreme conditions does not appear to have been objectively demonstrated by any commercially available suit as of the time of writing of this report. The best course of action for an individual in Arctic waters would be to remove themselves from the water as soon as possible and seek shelter from the wind and cold if possible.

Group Survival Kits

Power et al. (2016) compared the results from the work that calculated predicted survival time for a variety of clothing ensembles (Power and Monk, 2012) to the exposure times reported by Kennedy and colleagues (Kennedy et al., 2013) to compare the results. Power and et al. (2016) found that many of the garments tested were highly susceptible to wetting and wind, resulting in them not providing enough thermal protection to prevent death from hypothermia for the ETR (Power et al., 2016).

The results from the work by Power et al. (2016) appear to differ from those reported in SARex 2018 (Solberg and Gudmestad, 2018), even though the air temperature was warmer in the latter tests (-3°C) compared to the former (-15°C). In the SARex 2018 onshore abandonment exercise (Solberg and Gudmestad, 2018), participants started to abort the exercise as little as 12 hours after it started, while the results from the work by Power et al. (2016) suggest that under some circumstances the majority of people should have been able to "survive" until rescue arrived.

There exists some key differences between the two studies that highlight potential gaps in the performance of the equipment provided in the GSKs. First: the work by Power et al. (2016) showed that under only the most ideal conditions (dry, no wind) will the majority of the clothing ensembles provide a sufficient level of thermal protection to delay the onset of hypothermia until rescue arrives. As reported by the SARex 2018 authors, there was light snow with some wind at the start of the exercise, with "a little drizzle of rain" for a short period during the second day (Solberg and Gudmestad, 2018). As shown in Figure 8, the addition of wind and wetting of certain clothing ensembles will significantly reduce the thermal protection provided by them (and consequently decrease predicted survival time). If the clothing worn by the participants during the SARex 2018 (Solberg and Gudmestad, 2018) exercise did become wet, and were exposed to wind, then it is not unexpected that some participants had to abort the exercise early.

Another difference between the two bodies of work is that Power et al. (2016) calculated predicted survival times – the length of time it would take for someone to perish from hypothermia. The SARex participants had the option of aborting the exercise if they became too uncomfortable with the conditions. There is a considerable amount of time between beginning to feel uncomfortable due to the cold, and succumbing to the effects of it.

The last difference to note between the two studies is that the predicted survival times calculated by Power et al. (2016) were for stationary individuals, while it was reported that the participants who lasted for the SARex 2018 exercise performed periods of physical activity to increase their heat output (Solberg and Gudmestad, 2018). As the authors of the SARex 2018 work noted: the participants were aware of the "short" duration of the exercise and thus increased their physical activity to stay warm (Solberg and Gudmestad, 2018). It was unknown if people would be able to consistently perform this level of physical activity if they were required to await five days for rescue.

While it initially appears that the work by Power et al. (2016) differs from the SARex 2018 (Solberg and Gudmestad, 2018), the results from both bodies of work complement each other. The predicted survival times reported by Power et al. (2016) that allowed people to survive until rescue were only under the most ideal conditions. In the SARex 2018 exercises, the conditions were not ideal which saw people having to abandon the tests. The people who did manage to stay on the beach had to perform exercise to increase their heat output to compensate for the greater heat loss from the clothing they were wearing.

Tables 4 and 5 list the equipment suggested by the Polar Code that should be considered to help increase the survivability of people in the Arctic.

Table 4: Sample personal survival equipment as suggested by IMO Polar Code.

Suggested Equipment
Protective clothing (hat, gloves, socks, face and neck protection, etc.)
Skin protection cream
Thermal protective aid
Sunglasses
Whistle
Drinking Mug
Penknife
Polar survival guidance
Emergency food
Carrying bag

Table 5: Sample group survival equipment as suggested by IMO Polar Code.

Suggested Equipment
Shelter – tents or storm shelters or equivalent – sufficient for maximum number of persons
Thermal protective aids or similar – sufficient for maximum number of persons
Sleeping bags – sufficient for at least one between two persons
Foam sleeping mats or similar – sufficient for at least one between two persons
Shovels – at least 2
Sanitation (e.g. toilet paper)
Stove and fuel – sufficient for maximum number of persons ashore and maximum anticipated time of rescue
Emergency food – sufficient for maximum number of persons ashore and maximum anticipated time of rescue
Flashlights – one per shelter
Waterproof and windproof matches – two boxes per shelter
Whistle
Signal mirror
Water containers and water purification tablets
Spare set of personal survival equipment
Group survival equipment container (waterproof and floatable)

It is difficult to determine if the level of thermal protection offered by the suggested personal survival equipment listed in Table 5 is sufficient to delay the onset of hypothermia until rescue arrives. The term “protective clothing” offers no definitive measure of thermal protection and therefore opens itself up to interpretation. There exists a wide range of hats, gloves, socks, etc. available for purchase that offer various levels of thermal protection. An inexpensive set of cotton gloves will provide significantly less thermal protection than a high quality, name brand pair of mittens, but can still meet the Polar Code requirements.

Referring back to the work by Power and Monk (2012), the closest equivalent to the Polar Code recommended personal survival equipment that the authors tested would be the Abandonment Wear 1a[11] ensemble (Figure 12). Figure 8 shows that only under the most ideal circumstances (dry, no wind) does the Abandonment Wear 1a ensemble provide a sufficient level of thermal protection to generate a predicted survival time greater than 36 hours, thus meeting the Polar Code requirement of five days for the most vulnerable group of individuals. The minimum clo value[12] measured by Power and Monk

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[11] Refer to Appendix A for a description of this clothing ensemble.

[12] One clo is equivalent to the amount of insulation required to keep a seated individual comfortable in 21°C air, less than 50% relative humidity, and an air velocity of 0.1 $m \cdot s^{-1}$ (Golden and Tipton, 2002).

(2012) that provided a sufficient level of thermal protection against hypothermia was ~ 2.7 clo. This clo value should be considered the minimum needed for any clothing ensemble intended to be provided to people who have to survive in Polar Regions, with an air temperature of -15°C, until rescue arrives. Out of all the clothing ensembles tested by Power and Monk (2012) this clo value was only obtained by the majority of them under ideal conditions (e.g. dry, no wind). Therefore, a shelter of some kind (tent, liferaft, etc.) to keep a person dry and out of the wind would be essential for ensuring a person can be protected from hypothermia until rescue arrives. Another important factor to consider is that this estimated minimum value of ~2.7 clo was calculated assuming an air temperature of -15°C; if the environment was colder than this, a higher clo value would be needed to ensure protection from hypothermia.

Figure 12: Abandonment Wear 1a worn by a thermal manikin.

Even though the Abandonment Wear 1a ensemble provided a sufficient amount of thermal protection in the Power and Monk (2012) tests, it consisted of high quality, name brand clothing. As well: all predicted survival times were generated assuming an ambient air temperature of -15°C. The MDLT shown in Figure 3 indicates that these air temperatures are only observed from Jun – Sep for the majority of the eight locations, coinciding with the primary shipping season. If the air temperature is lower than -15°C during those periods, then the predicted survival times will be lower as well.

Availability of on Ice Abandonment Option

As prescribed in the Polar Code, one potentially available abandonment scenario that could occur in Polar Regions is evacuation onto the sea ice or onto land. This could either be direct evacuation onto the ice or initial evacuation into the water and then onto the ice or land. This is a very different scenario than survival in floating LSA, and its availability is dependent on the nature of the ice conditions present as well as the proximity and geography of the shore. Generally, evacuation onto land will only be available if the accident occurred relatively close to shore. Lifeboats may be able to make their way to shore if the sea along the way is ice free or the concentration is sufficiently low to allow forward progress. If significant pack ice or landfast ice exists, then it may not be possible to reach shore and therefore the survival will have to take place either in the LSA or on the ice.

Abandonment and survival on the ice may not always be possible. For example, if the sea ice is composed of broken ice with small floes, abandonment onto the ice would not be possible even if the concentration was high Also, the ice could have a relatively high concentration, but not thick enough to support the weight of the survivors and equipment, as would likely be the case in early stages of the winter season when the ice is still growing. Until the ice is thick enough to safely support the weight of the survivors and their equipment, abandonment onto the ice is not considered a viable option.

Since abandonment onto the ice or land is not always available for the abovementioned reasons, it should not be the one and only solution considered in the escape, evacuation and rescue (EER) strategy. Careful consideration of the actual range of potential environmental conditions including ice variability and dynamic behaviour is essential to ensure that the EER system is capable of being available in all potential scenarios.

If abandonment onto the ice or land is possible, shelters would need to be available to remove survivors from the elements. As can be seen in the “Gap Analysis of Estimated Exposure Time and Life Saving Appliance Performance” section of this report, not being able to seek shelter and being exposed to the elements would significantly impact survivability. Emergency shelters would be typically provided in the GSKs. However, the SARex 2018 (Solberg and Gudmestad, 2018) report demonstrates that such evacuation shelters could be difficult to erect. If the LSA includes life rafts, it may be possible to pull these onto the ice or land and use them as shelters. During the SARex 2018 (Solberg and Gudmestad, 2018) exercise, life rafts were the preference over the supplied shelters that were provided specifically for this purpose. Currently there are no lifeboat technologies that are intended to be deployed directly to the ice, or that can be pulled onto the ice that are presently used on board vessels, so any on ice survival would require the use of supplied shelters in the GSKs, designed for onshore or on ice survival scenarios.

Summary of LSA Availability in Different Ice Conditions

Table 6 provides a summary of the approximate LSA performance or estimated availability as a function of typical ice conditions expected at different periods of the year, based on the studies reviewed in this section. According to this table, the suitability of LSA equipment and abandonment scenarios are highly dependent on the ice conditions that exist at the site. As ice conditions can be highly dynamic, the availability can also fluctuate in relatively short notice. Consideration of the above scenarios needs to be considered when selecting LSA equipment as well as developing the evacuation strategy. For example, referring to Table 6, it is most likely that a lifeboat would only be able to make forward progress through the water when ice concentrations are low during the late spring, and summer seasons (indicated by green). Outside of those seasons, the ice concentrations would most likely be too high for the lifeboat to be able to move through (indicated by red).

Table 6: LSA performance, or estimated availability, in varying ice conditions (ignoring temperature). Legend: green = performance likely to be adequate; yellow = performance may not be adequate; red = performance not adequate.

		Generic Ice Season					
	Description	**Winter**	**Early Spring**	**Late Spring**	**Summer**	**Freeze Up**	**Early Winter**
	Thickness	**Thick**	**Thick**	**Thick**	**Thick**	**Thin**	**Thick**
	Floe Size	**Large**	**Large**	**Large**	**Small**	**Large**	**Large**
	Concentration	**>9+/10ths**	**8-9/10ths**	**5-7/10ths**	**0-4/10ths**	**8-9+/10ths**	**>9+/10ths**
Scenario	**Lifeboat ability to make forward progress**	🟥	🟥	🟩	🟩	🟥	🟥
	Lifeboat ability to provide shelter	🟥	🟥	🟩	🟩	🟨	🟥
	Liferaft ability to make progress	🟥	🟥	🟨	🟩	🟥	🟥
	Liferaft ability to provide shelter (in water or on ice)	🟩	🟩	🟨	🟩	🟨	🟩
	On Ice Abandonment	🟩	🟩	🟥	🟥	🟥	🟩

Polar Code LSA Performance Requirements

With the performance of LSA compared against ETR, we are now able to address the following questions:

Does the Polar Code demand a sufficient level of performance from LSA to keep people safe for the estimated exposure time?

In its present form, the wording of the Polar Code does not specifically indicate a level of performance that would be necessary to ensure survival in the Canadian Arctic for the expected time of rescue. In addition, the Polar Code does not have any testing requirements to ensure that the equipment is functional in the range of conditions that a vessel may be operating in. The Polar Code states that LSA must perform to a level sufficient to keep people alive for a minimum of five days while they await rescue, but it is left up to the operators to determine what that required level of performance actually is. There exists a lack of specific guidance in the Polar Code to make recommendations on what equipment should be used for specific conditions. While this was an intentional decision to provide a degree of flexibility that allows operators to utilize an appropriate level of LSA proportional to the conditions they are operating in, based on their Risk Assessment, this also allows for individual interpretation on what can be considered appropriate. For example, the personal equipment listed in Table 4 has no thermal insulation values assigned to it and therefore lends itself to a wide degree of interpretation. The results from SARex 2018 show that some of this equipment was not sufficient for some people to “survive” for even 24 hours on a beach (Solberg and Gudmestad, 2018), let alone the Polar Code requirement of five days.

Do LSA performance benchmark values as reported in the literature meet the ETR?

Based on the studies reviewed for this report, the performance of existing LSA is not sufficient to meet the ETR in the Canadian Arctic.

As shown in the SARex 2016 and 2018 exercises, current off the shelf (COTS) survival craft or even GSKs are insufficient at providing a survivable condition for the participants. In the SARex 2016 (Solberg et al., 2016) exercises, participants began to leave the liferaft after only six hours, and no one was able to stay in the liferaft for more than nine hours without showing symptoms of hypothermia. In the lifeboat, occupants started to abandon the test after approximately seven hours. When compared to the minimum requirement of five days, both survival craft fall short significantly. It was only when winterized equipment was used during the SAREX 2017 trials did we begin to see a better level of performance, but the trials were only conducted for 24 hours, much shorter than the five day minimum requirement as specified in the Polar Code.

In the SARex 2018 (Solberg and Gudmestad, 2018) onshore abandonment exercise, survivors started to abort the exercise as little as 12 hours after it started. Therefore, the test clearly shows that the equipment provided was insufficient in ensuring that a suitable survival environment was provided for all, let alone for the expected time of rescue five day minimum requirement.

Based on the research performed for lifeboat testing in ice, it appears that existing COTS lifeboats would likely not be able to hold up to significant pack ice scenarios (particularly high concentrations of thick, converging ice) in the Canadian Arctic for the expected time of rescue, though it would likely be acceptable in low to moderate concentrations and through prudent operation of the craft.

Though not explicitly considered in this study, rescue boats such as rigid-hulled inflatable boats (RHIBs), like lifeboats, are typically not designed for operations in ice. Therefore, the Risk Assessment and marine evacuation system strategy should carefully consider the recovery operation, including how survivors will be transferred from the survival craft/site to the rescue vessel. The expected time of rescue should also factor in amount of additional time required to recover all survivors in such scenarios.

If LSA performance benchmark values are not sufficient to meet estimated exposure time, identify new technologies, strategies, or requirements to meet them.

As discussed in the “Gap Analysis of Estimated Exposure Time and Life Saving Appliance Performance”, conventional COTS LSA will not be able to provide a habitable environment to ensure that all survivors can survive to the expected time of rescue in the full range of environmental conditions expected in the Canadian Arctic. If vessels were limiting their Canadian Arctic voyages to the summer season, when the ice concentration is low and air temperatures around the freezing mark, winterized equipment such as that used in SARex 2017 may be sufficient. . Such equipment needs to be carefully considered on a case by case basis, and the full range of potential environmental conditions that can occur including their dynamics needs to be considered. For example, the evacuation may take place in an area of low ice concentration, but the concentration can increase rapidly if winds suddenly change and pushes the ice to the shore.

While there are a number of emerging technologies and concept designs for survival craft that address many of the functional limitations that currently are not achievable with COTS equipment (such as the Ice Strengthened Lifeboat and Arktos), overall technological development progress has been slow. This is not due to lack of innovative LSA equipment manufacturers; it is the lack of regulatory requirements to ensure survivability in such conditions. Without strict regulatory requirements in place to demand a higher level of performance, the incentive for LSA manufacturers to develop new technologies to improve LSA performance is relatively low, as ship operators may opt for lower cost solutions that still meet existing requirements.

As described in the “LSA Regulatory Requirements in the Canadian Arctic”, new guidelines are currently under development to support Chapter 8 of the Polar Code (IMO SSE 6/5). Key considerations include the development of quantitative benchmarks regarding design of LSA (similar to SOLAS LSA code), and the development of requirements for testing of LSA in the range of conditions expected, including down to the PST. It is expected that these new requirements should improve the overall performance of LSA in Polar Regions; providing critical guidance to LSA equipment manufacturers as well as the evaluation of the LSA kit in the Risk Assessment should help to ensure that the provided marine evacuation system (MES) is adequate for the vessel’s intended operation. However, it is not clear how the full range of environmental conditions will be taken into account in the development and testing of the LSA equipment. The conditions to be tested as well as the testing approaches need to be clearly defined, sufficient, and representative of the expected functionality during an actual abandonment scenario. Until requirements in the regulations move from prescriptive to performance based, the technological advancement of LSA technology for Polar Regions, specifically operability in pack ice, is expected to be reactive rather than proactive.

Examples of areas in particular that should be considered include:

1. The Risk Assessment should consider abandonment scenarios in the full range of ice conditions present, and solutions need to be developed to match. This could include different combinations of LSA equipment, and survival strategies.
2. If pack ice is present, the potential unavailability for direct abandonment directly onto the ice or on-ice survival needs to be considered, as it will be fully depending on the nature of the ice conditions present (ice thickness, concentration, floe size, etc.). Also, consideration of the ice dynamics need to be taken into account, as converging or diverging pack ice can significantly impact functionality of the LSA equipment and correspondingly the survivability of survivors. If direct abandonment onto the ice is not possible, then the functionality of survival craft in expected pack ice conditions as well as decision matrix need to be considered.
3. Ensuring that the supplied personal LSA, including thermal protective aids, provide a level of thermal protection to allow sedentary individuals to remain in thermal balance for the given environmental conditions they may be exposed to, as well as protection of the limbs to prevent frostbite or loss of dexterity.
4. LSA should have an integrated heat source to maintain internal temperature of the survival craft, and should not need to rely on body heat of occupants for this. The number of occupants should not detrimentally influence the chances of survival of each individual.

5. Heating sources (either in the survival craft or in the on ice/land shelters) need to be safe to use inside the shelter and have a sufficient rating and fuel capacity to maintain some minimum acceptable internal temperature, down to the PST for the EET.
6. Survival craft, as well as the shelters, need to be functional and easy to use wearing the personal LSA supplied down to the PST, for at least the EET.
7. All components in the MES need to be considered to ensure functionality of the system as a whole, in all possible conditions, including PST, for the EET.
8. Crew members that will be expected to lead and manage the survival effort shall have sufficient training in survival skills, use of the equipment and evacuation plan.

Recommendations for LSA used in Polar Regions are therefore as follows:

1. Lifeboats intended for use in Polar Regions should be designed for and tested in the relevant conditions, such as low temperatures and the presence of ice.
2. Clothing ensembles with a minimum clo value of 2.71 clo for regions with an ambient MDLT of -15°C are recommended. Therefore, a higher clo value should be required for regions with lower average temperatures. The clothing ensembles must be water and wind resistant to maximize effectiveness.
3. A heating system providing the ability to maintain a minimum internal temperature of 10°C in a survival craft is recommended. The interior temperature should be monitored in real time. As well, the required temperature will vary depending on clothing worn inside the craft; occupants wearing clothing with a higher clo value will result in a lower temperature required inside the craft (Power, 2018).
4. The survival craft and/or shelters should have an adjustable ventilation system designed to provide sufficient air quality at all times, ensuring an eight hour time weighted average (TWA) CO_2 concentration < 5,000 ppm, without compromising the thermal protection offered by the craft or shelter. The eight hour TWA CO_2 concentration of 5,000 ppm is the value recommended by the National Institute for Occupational Safety and Health (NIOSH) as the Recommended Exposure Limit (REL); the American Conference of Governmental Industrial Hygienists (ACGIH) as the Threshold Limit Value (TLV); and the United Kingdom (UK) as the Workplace Exposure Limit (WEL) (Scott et al., 2009).
5. In order to ensure that the air quality inside survival craft remains at safe levels (for both CO and CO_2) sensors should either be installed, or brought on board as hand held units, that allow real time monitoring. These sensors should have both an auditory and visual indicator to inform survival craft occupants when air

quality degrades to an unsafe level, thereby allowing them to manage the exchange of air with the outside environment at an appropriate level.

6. Life rafts, when used, should at minimum have an inflatable floor to improve thermal protection of the occupants. Occupants should also have access to high level PPE, such as immersion suits, inside the craft.

Recommendations for Future Work

While there is significant progress being made in the development of LSA requirements for Polar Regions, including the Polar Code and the current updates under consideration such as IMO SSE 6/5, there is still room for improvement. To support the updates that are currently under consideration, additional research is required to verify that LSA is functional in the range of potential environmental conditions that the LSA would be exposed to in an emergency abandonment scenario. This includes conducting additional practical field research exercises such as SARex (Solberg et al., 2016; Solberg et al., 2017; Solberg and Gudmestad, 2018), as well as scientific research. This work allows the lessons learnt (practical or scientific) to feed back into the regulatory development work, generally leading to improved LSA performance. For example, the research performed in the area of air quality inside survival craft have led to the development of draft requirements for dealing with identified problems, which will likely result in improvements to safety and overall habitability for survivors. Such anecdotal practical and scientific based research and experience needs to continue to improve LSA performance in the range of expected conditions expected in Polar Regions.

In terms of potential next steps beyond this study, the following activities are envisioned that can help close the gaps between LSA performance for operations in Polar Waters:

1. One of the significant challenges associated with executing this project is the lack of specific information on the environmental conditions being considered in the Risk Assessment, in which the customized LSA solution is based on. Such information was not readily available in the public domain and it was not readily clear how to obtain information on how equipment would be updated to meet specific functional requirements. As a result, it was very difficult to assess the suitability of the LSA used for the intended operation. Therefore, it is recommended that a study be conducted to evaluate LSA performance against the intended operation of the vessel, as outlined in the Risk Assessment. In this study, the team would review the Risk Assessments and Polar Water Operations Manuals submitted by multiple ship operators to receive a Polar Ship Certificate, and assess whether the LSA selected are sufficient to ensure survivability until the expected time of rescue for the intended operation.

2. The current study considered LSA performance for SOLAS vessels operating in the Canadian Arctic. Since the majority of vessel traffic in the Canadian Arctic are fishing vessels and pleasure craft, it is more likely that such would be involved in an emergency evacuation scenario. Since these vessels are non-SOLAS vessels, they do not need to comply with the Polar Code or Canadian

Arctic Shipping Safety and Pollution Prevention Regulations and therefore the LSA carried on board are not susceptible to the same level of functionality and performance requirements as those found on SOLAS vessels. A future study could investigate the LSA performance carried on board non-SOLAS vessels operating in the Canadian Arctic against the functional requirements needed to ensure survivability until the expected time of rescue.

3. As discussed, the estimated exposure times reported by Kennedy (Kennedy et. al, 2013) was limited to the month of August, which are considered ideal conditions. For the remainder of the year, it is expected that the response times for marine rescue assets in particular could be much longer, mainly due to the increased severity of the sea ice and significantly reduced number of potential rescue assets. . A potential next step would be to consider potential rescue response times during periods other than the ideal midsummer season, when fewer assets are available and the ice conditions are more severe. This would help provide a more realistic estimate of the expected time to rescue that would be required in the Canadian Arctic given current SAR capabilities at different periods of the year.

4. The SARex programs conducted to date used human participants that were relatively young and fit, which is not representative of the general health condition of the passengers on board cruise vessels. Given this, it may be possible to investigate the survivability of typical cruise ship passengers when exposed to Arctic like conditions such as low temperatures and high winds, and evaluate whether existing LSA used for Polar Water operations is sufficient for the less than ideal though typical human demographics.

5. Continued testing of LSA equipment in simulated Arctic conditions. As discussed in this study, the full scale trials and model test programs performed to date have significantly contributed to the knowledge base of the performance and limitations of survival craft in harsh environmental conditions. The lessons learnt from such programs have significantly contributed to the development of regulations as well. Due to the importance of such information collected, the authors recommend that further research is performed to further investigate the performance of LSA in harsh conditions. These lessons would be available to continue with updating regulatory regime as well as update LSA technology and strategies, resulting in an overall increase in marine safety. For example: there exists little work that has examined the operational performance and availability of liferafts in ice covered waters. Quantifying the limitations of liferafts in ice covered waters (e.g.: at what concentrations would it be unsafe

to tow them) would be invaluable in determining if, and when, they should be deployed in Polar Regions.

6. Further investigate the feasibility of current LSA concept designs that have been developed specifically for operating in harsh environments such as the Canadian Arctic. This could include further data collection and analysis to further develop the concepts and confirm whether they would be suitable for ensuring survival in the range of conditions experienced in the Canadian Arctic for the expected time of rescue.

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Appendix A – Clothing Descriptions

Ensemble	Description
Cabin Wear	Denver Hayes JMC61001 denim jeans; Cherokee 100% cotton long sleeve flannel shirt; 90% cotton socks (9% nylon + 1% Lycra Spandex); Denver Hayes 100% cotton boxer shorts; Dakota Style #MDNS308NST leather shoes.
Deck Wear	Cabin Wear plus : Stanfield's long underwear (long sleeve shirt [6623] and pants [6602]); Helly Hansen soft pile jacket and pants; Helly Hansen compass jacket (AJ301) and pants (U310); Wind River toque (style 47-2694HH with fleece lining), Wind River mittens (style 71-9-85905).
Expedition Wear #1	Deck Wear plus: wool socks and Baffin Industrial ASTM 2413-05 Polar proven -40°C with five layer liner.
Expedition Wear #2	Expedition Wear #1 except: Helly Hansen compass jacket and pants replaced by Mustang Survival MS195 HX Integrity Suit (XL).
Abandonment Wear 1a	Deck Wear plus: Helly Hansen P2000 Passenger Suit/Thermal Protective Aid; SOLAS life vest (Lalizas 70169 BV) (gloves replaced by fleece mittens because TPA has gloves); wool socks.
Abandonment Wear 1b	Deck Wear plus : Mustang Survival Coverall (once only suit) Anti-exposure model MSD685; SOLAS life vest (Lalizas 70169 BV) (gloves replaced by fleece mittens because TPA has gloves); wool socks.
Abandonment Wear 2	Deck Wear with wool socks minus footwear plus Mustang SOLAS immersion suit, SOLAS life vest (Lalizas 70169 BV) (gloves replaced by fleece mittens because immersion suit has gloves); wool socks.
MAJAID #1	Cabin Wear without Dakota Shoes; parka; pants; mittens; toque; boots.
MAJAID #2a	MAJAID #1 ensemble inside down filled casualty bag.
MAJAID #2b	MAJAID #1 ensemble inside synthetic filled casualty bag.

Appendix B – Ice Concentrations for Each Location

Table 7: WMO colour codes used in ice concentration figures.

Color	Concentration Range	CIS Description
⬜	C = 0	Ice Free
🟦	0 < C ≤ 1/10ths	Open water
🟩	1 < C ≤ 3/10ths	Very Open Ice
🟨	3 < C ≤ 6/10ths	Open Ice
🟧	6 < C ≤ 8/10ths	Close Ice
🟥	8 < C < 10/10ths	Very Close Ice
⬛	C = 10/10ths	Fast Ice

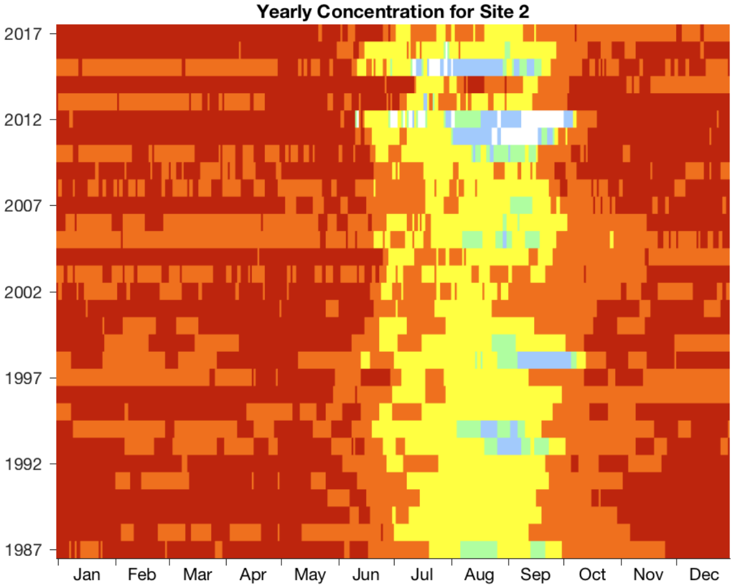

Figure 13: Yearly ice concentrations for location 2.

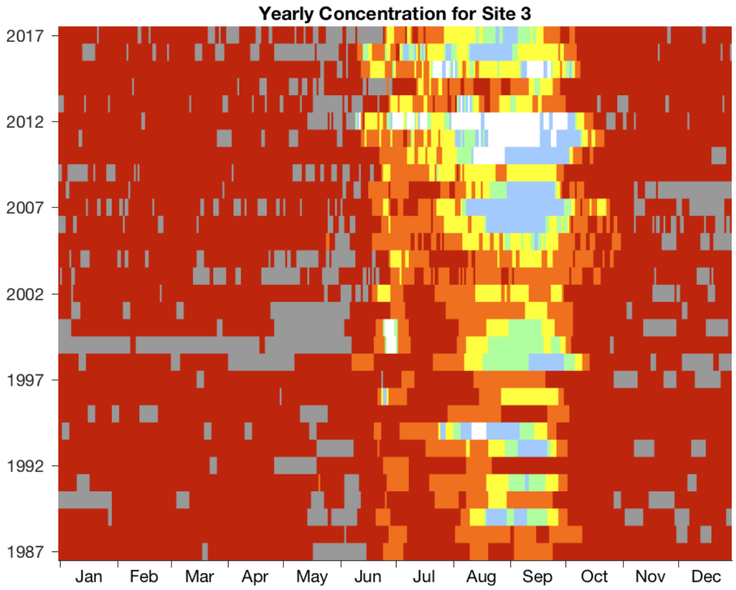

Figure 14: Yearly ice concentrations for location 3.

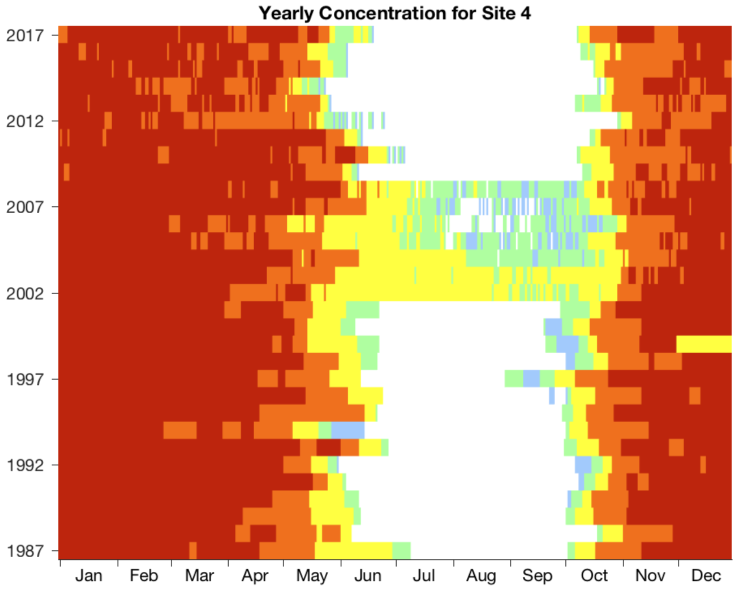

Figure 15: Yearly ice concentrations for location 4.

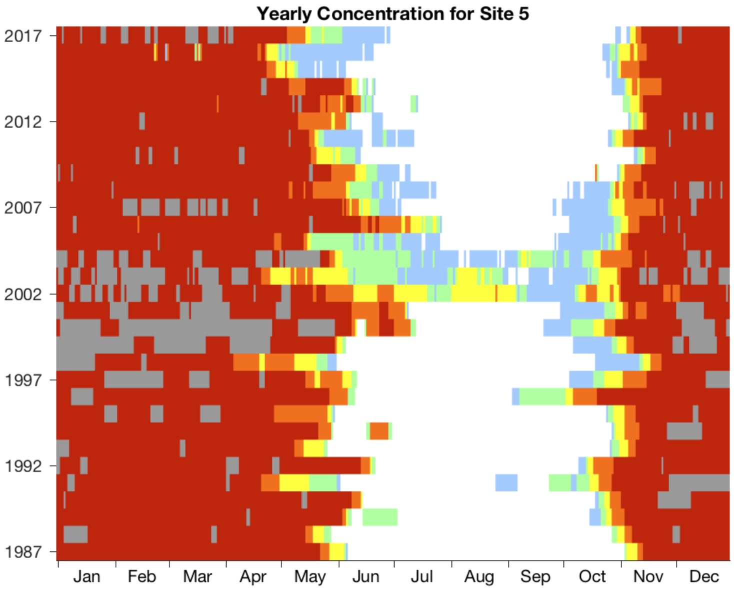

Figure 16: Yearly ice concentrations for location 5.

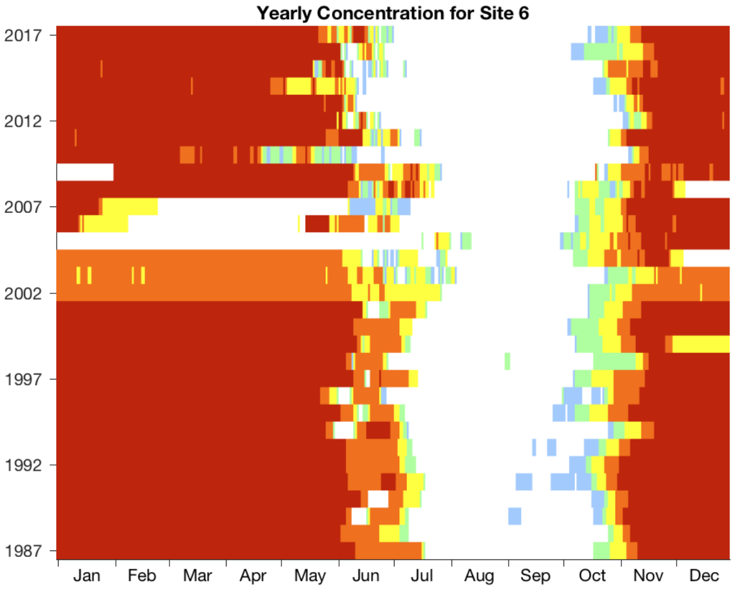

Figure 17: Yearly ice concentrations for location 6.

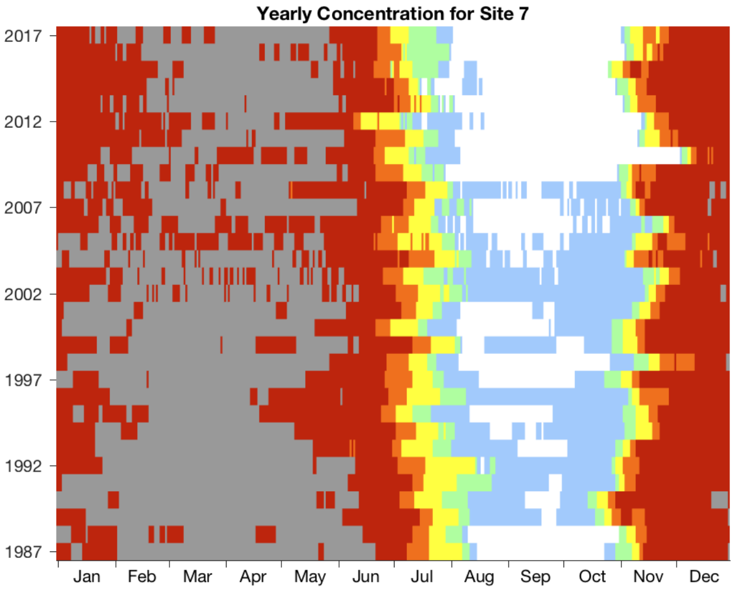

Figure 18: Yearly ice concentrations for location 7.

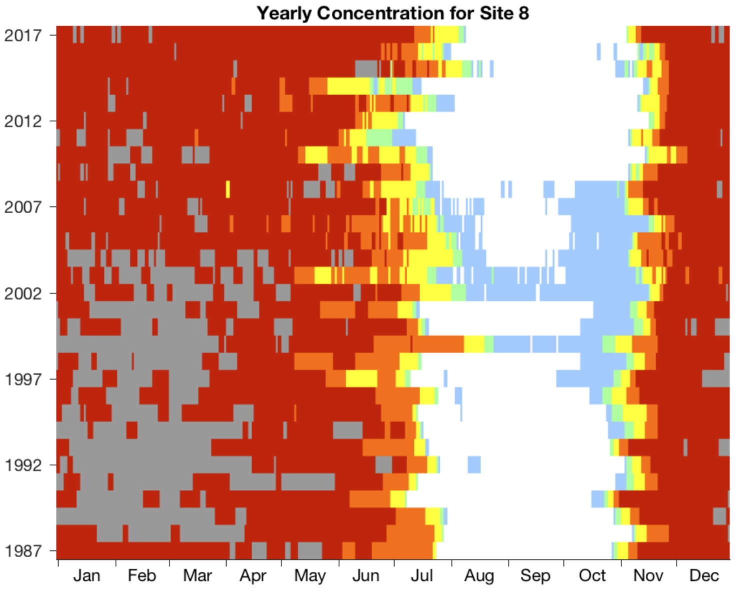

Figure 19: Yearly ice concentrations for location 8.