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Title: The role of environmental factors in search and rescue incidents in Nunavut, Canada

Authors: Clark, Dylan G. (dylan.clark@mail.mcgill.ca)[a]; Ford, James D.[a]; Berrang-Ford, Lea[a]; Pearce, Tristan[b,c]; Gough, William[d]; Kowal, Slawomir[d]

Author Addresses: (a) Department of Geography, McGill University, Montreal, QC, Canada (b) Sustainability Research Centre, University of the Sunshine Coast, Sippy Downs, Qld, Australia (c) Department of Geography, University of Guelph, ON, Canada (d) Department of Physical and Environmental Sciences, University of Toronto, Scarborough, ON, Canada.

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Abstract

Objectives: Unintentional injury is a leading cause of morbidity and mortality in Nunavut, where the importance of land-based activities and reliance on semi-permanent trails creates unique risk profiles. Climate change is believed to be exacerbating these risks, although no studies have quantitatively examined links between environmental conditions and injury and distress in the Canadian Arctic. We examine the correlation between environmental conditions and land-based search and rescue (SAR) incidents across Nunavut.

Study design: Case study

Methods: Case data was acquired from the Canadian National Search and Rescue Secretariat. Gasoline sales from across the territory are then used to model land-use and exposure. We compare weather and ice conditions during 202 SAR incidents to conditions during 755 non-SAR days (controls) between 2013 and 2014.

Results: We show daily ambient temperature, ice concentration, ice thickness, and variation in types of ice to be correlated with SAR rates across the territory during the study period.

Conclusions: These conditions are projected to be affected by future climate change, which could increase demand for SAR and increased injury rates in absence of targeted efforts aimed at prevention and treatment. This study provides health practitioners and public health communities with clearer understanding to prepare, respond to, and prevent injuries across the Arctic.

Keywords: Arctic; search and rescue; injury; climate change

Highlights

- Use of gasoline sales is proposed as a control for hazard exposure and land-use
- Environmental conditions of days with a SAR are compared to conditions of control days
- Ice conditions and daily temperatures are shown to influence risk of SAR and injury

Introduction

Injury is the leading cause of death for Canadians age 1 to 44, costing an estimated $26.8bn annually.[1] The burden of injury and trauma disproportionately affects socially marginalized populations,[2-4] and Indigenous populations in the Arctic have been identified as being particularly susceptible given social and environmental contexts.[5-7] Mortality rates of unintentional injury in the Inuit territory of Nunavut, for example, are more than twice the national average, and potential years of life lost (2,763 per 100,000) more than three-times the national average.[8, 9]

Climate change may further amplify injury rates in the Canadian Arctic, given the strong relationship between Inuit and the land for culturally-valued harvesting activities and transport between communities on semi-permanent ice and land-based trails.[5, 10, 11] Over the past century in the Arctic, average surface air temperatures have increased by 5^{o}C, and perennial sea ice has declined by 9-14%;[12] Temperatures are projected to increase by an additional 2^{o}C to 9^{o}C this century, with wide ranging impacts.[13] Research suggests that more dynamic ice conditions and increasing unpredictability of the weather are increasing the risk of injury and raising demand for search and rescue (SAR) across the North.[14, 15] No studies in the Canadian Arctic, however, or more broadly, have quantitatively examined links between environmental conditions and injury or SAR. This paper examines the correlation between environmental conditions and SAR incidents across Nunavut, comparing weather and ice conditions during 202 SAR incidents to conditions during 755 non-SAR days (control) between 2013 and 2014.

Previous Arctic land-injury research has relied on descriptive analysis to understand patterns of injury due to a lack of case and exposure data.[5, 9, 14, 15] However, by not accounting for exposure or quantity of travel on land, sea, or ice – termed land-use – previous studies do not capture links between environmental risk and injury. Without controlling for exposure, studies could simply be capturing fluctuations in land-use intensity, not risk. In this study, we develop a new methodology for modeling land-use (exposure) in the Canadian Arctic using gasoline sales, and test for an association between weather/ice conditions and SAR demands across Nunavut, controlling for exposure to hazards. Furthering knowledge of injury pathways in general, and related to environmental factors in particular, the work is important for informing public health and medical practitioners in remote northern communities on prevention and response. Increased knowledge of when and under what conditions injuries occur can help health care practitioners focus preventions and prepare treatment resources.

Methods

The Canadian Territory of Nunavut (population 31,905) is located in the eastern Canadian Arctic, stretching from the Hudson Bay to Greenland, including 25 communities ranging in size from 130 to 6600 people.[16] Caribou, seal, polar bear, walrus, narwhal, and whales inhabit the region, migrating seasonally and providing sustenance for Inuit in the region.[17] Inuit make up 83% of the territory's population. Over the past half-century, Inuit livelihoods have been dramatically altered, including moving into fixed settlements, residential schools, introduction of the wage economy, and new governance arrangements.[18, 19] Despite these and other changes, hunting and travelling on the land remain a vital component of food security and cultural identity for the majority of families in Nunavut.[20, 21] Though these activities are prohibitively costly for some, many still go out on the land, particularly on weekends. Snowmobiles, all-terrain vehicles (ATVs), and boats are used for travel outside of the twenty-five hamlets in Nunavut. Hunters, fishers and trappers go out for various lengths of time, ranging from a day to weeklong trips. In addition to hunting, fishing and trapping, travel between hamlets is common.[22]

Land activities carry inherent risk in the Arctic environment. Hunters who travel to the floe-edge (where sea meets ice) can become stranded if ice breaks off with a changing tide or gale. Cold temperatures and open water can cause hypothermia within minutes during much of the year. Definitive care typically requires aeromedical evacuation south, an activity also dependent on weather. In 2015, medical travel cost the Government of Nunavut $66.3 million, roughly 25% of health service expenditures[23].

When individuals are overdue or call for help, community SAR operations are activated. Search and rescue across Nunavut is largely conducted by hamlet-based SAR committees, and supported by the Canadian Armed Forces (CAF) and the Canadian Air Search and Rescue Association (CASARA). Operations are overseen by Nunavut Protection Services, with the Royal Canadian Mounted Polices serving as a liaison between the hamlets and the Government of Nunavut. In this context, informed prevention – built on understanding of the causes or injury and distress on the land – saves lives and money.

In the context of injury risk, individual exposure is based on exposure to land hazards. Modeling exposure to hazards has long been a challenge for injury research,[24] and is particularly problematic in the Northern context. Land travel in Nunavut is influenced by decisions related to animal migration, weather and ice conditions, work schedules, and financial constraints. We thus developed a method to proxy land-use intensity using gasoline sales from each community, thereby estimating hazard exposure. Gasoline is used for all-terrain vehicles, snowmobiles, boats, small engines (snowblowers and ice augers), and automobiles (noting there are no permanent roads between Nunavut communities). Individuals generally fill up their snowmobiles, ATVs, or boats just before leaving for a trip.

We accessed gasoline sale data through the Government of Nunavut Petroleum Products Division. The database detailed each individual sale and the liters purchased, by hamlet from January 1, 2013 to December 31, 2014 (i.e. the study period). Automobiles are a chief consumer of gasoline in Nunavut communities, and not associated with land-use. Thus, it was necessary to eliminate automobile gasoline use. This was done by excluding purchases exceeding 50 liters. The majority of snowmobiles used in Nunavut have a capacity of 30 – 40 liters of gasoline and can go as far as 200km on a tank depending on conditions and sled weight; ATVs have capacities less than 20 liters, although users often take an additional 20 liter tank on medium length trips. Boats vary widely in consumption based on vessel length and engine size and conditions, however a 50 horsepower medium-size craft could generally travel for three hours on less than 50 liters of gasoline. Cars and trucks common to Nunavut communities generally have tanks greater than 50 liters, many with tanks over 75 liters. The 50 liter threshold was also informed by consultation with gasoline station workers and community residents.

To ensure that gasoline purchases were not reflecting cash availability in households rather than days with higher land-use, we examined purchases for pre-identified biweekly spikes due to receipt of government vouchers and pay cheques. We used a moving average to account for short delays between purchase and land-use and for the duration of hazard exposure during multi-day trips.

We aggregated sales by day for each hamlet during the two-year period. After applying a three-day moving average, the 70 days (top 10%) with the most sales from each community were selected as control days. Days represented high land-use with no SAR. The cutoff was selected for an optimal sample size while maintaining certainty of proxied control days. Gasoline sales were not available for the community of Cambridge Bay. Subsequently, control days were not selected from the hamlet. Additionally, control days were not selected for Iqaluit because of higher rates of motorized vehicles use around town and assumed resulting inaccuracies of gasoline estimates.

The National Search and Rescue Secretariat provided SAR data from years 2013 and 2014 (n=336). Search data prior to 2013 had not been collected by the agency. The SAR data used had associated descriptors of the incident coordinates, time of search initiation, event severity, event type, and rescuing authority; however, inconsistent data prevented regression analysis beyond time and place. All false alarms (intentional and unintentional) (n=16) and all SAR events precipitated by an aviation crash were removed (n=32). Additionally, multiple incidents that occurred on the same day and location were only counted as one (n=19). We assumed that while weather may contribute to aviation hazard, the causal pathways would be different to land-use hazards.

We retrieved weather data for the two-year period from Environment Canada's online databases. Daily weather conditions were retrieved for each hamlet over the period. Variables recorded included: minimum daily temperature and presence of a wind flag (wind speed >30kph).

Ice conditions were retrieved from Environment Canada's online ice database. Surrounding each hamlet (excluding Baker Lake, which is land-locked) (n=24), three measurement points were chosen at increasing distances from the shore. Ice concentration, partial concentration, ice thickness, and ice type were recorded for all 72 points.[25] Numerous points were chosen for each community to account for a variety of travel routes and hunting locations. While it was not possible to verify all point locations with locals, the locations were acknowledged by resident land-users to be representative of potential travel routes in communities where we conducted more in-depth qualitative examination of SAR. We calculated daily means of the three ice points to obtain a daily average for each variable per community.

We matched each proxied control and SAR case day with the respective environmental conditions on the day in the community. The dataset was compiled using R statistics.[26, 27] We removed days with no available weather and or ice data (n=67 case and n=323 control); the final dataset comprised 202 case days and 755 control days. We used multivariable fractional polynomial regression to test for an association between each environmental condition and SAR days.[28] Minimum daily temperature, daily wind flag, ice mean thickness, mean partial concentration, and mean number of ice types were tested as independent variables. We used a binary outcome for the dependent variable, indicating whether a SAR operation occurred or not.

We built the regression model on theoretical understandings from the literature of land, sea, and ice hazards in the North. Using a base logistic regression model, environmental variables were regressed against a binary case variable. We chose a nonlinear relationship between temperature and hazard because of expected risk associated with moderate temperatures (-10^{o}C to 5 ^{o}C). We chose to account for the non-linear relationship with a multivariable fractional polynomial regression, hypothesizing a polynomial curve that would peak around 0 ^{o}C.

We conducted sensitivity analysis for the three-day moving average, selection of top 10% of gasoline purchase days, and use of minimum temperature over mean temperature. Further, any temporal autocorrelation that may have been exhibited in independent variables or case data would have been eliminated with the case control approach.

Results

Proxied land-use based on gasoline sales increased on the weekends, with a smaller increase in the middle of the week. Proxied land-use varied throughout the year across the Territory (Figure 1); however, patterns shifted per community and latitude.

The frequency of search and rescue incidents follows similar trends to land-use, with peaks on Sunday and Wednesday, and in the spring and fall. However, weeks with the highest frequency of SAR events in the spring are about four weeks after the proxied land-use spring peak. Most searches were due to mechanical breakdown and did not result in loss of life (Table 1).

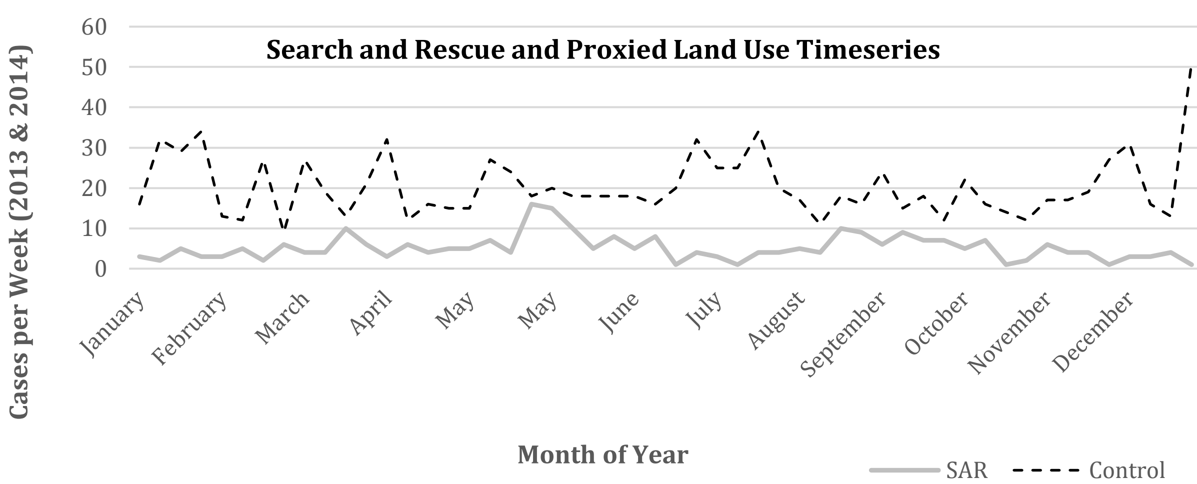

Figure 1. Count of search and rescue cases and selected control days (days when people are likely on the land based on gasoline sales) per month for 2013 and 2014.

Table 1: Summary of the 2013 and 2014 search and rescue cases in Nunavut. Data were reported by SAR organizations and collected by the National Search and Rescue Secretariat.

SAR Event	Sample Size	Percentage
Severity		
Unknown	110	54.5%
Assistance is required, but no distress exists	56	27.7%
Strong potential for loss of life	11	5.5%
Life in imminent danger	11	5.5%
Other	14	6.9%
Cause		
Unknown	118	58.4%
Mechanical breakdown	30	14.9%
Ran out of fuel	12	5.9%
Weather	6	3.0%
Medical	6	3.0%
Lost	6	3.0%
Stranded/Stuck	5	2.5%
Broke through ice	5	2.5%
Other	14	6.9%

Multivariable fractional polynomial regressions demonstrated that weather and ice conditions were associated with the odds of a SAR event occurring (Table 2). As hypothesized, the relationship between temperature and risk was non-linear. The multivariable fractional polynomial regression fit temperature variables as Temp 1: $((x+43.6)/10^3)$, and Temp 2: $((x+43.6)/10^3)*\log(x+43.6/10)$. The relationship reflected increasing risk as daily minimum temperature approached -3 °C, and declining risk for days with warmer minimum temperature. All other independent variables were held linear by the model. Higher concentrations of ice in an area (mean ice partial concentration) was also associated with increased odds of a SAR event. A greater variety of ice types and increased ice thickness was associated with reduced odds of a SAR event. Wind was not significantly associated with the odds of a SAR event (see Fig. 2).

Table 2: Multi factorial regression analysis of 2013-2014 search and rescue cases in Nunavut and environmental factors.

	OR	CI-2.5%	CI-97.5%
Minimum daily temperature			
Temp 1 ((x+43.6)/10³):	1.2***	1.1	1.2
*Temp 2 ((x+43.6)/10³)*log(x+43.6/10):*	0.9***	0.9	0.9
Mean ice partial concentration	1.2***	1.1	1.4
Mean ice thickness	0.9**	0.9	0.9
Variety of ice types	0.6*	0.5	0.9
Wind flag	1.0	0.7	1.4

*p value '***' < 0.001, '**' < 0.01, '*' < 0.05, '.' <0.1*

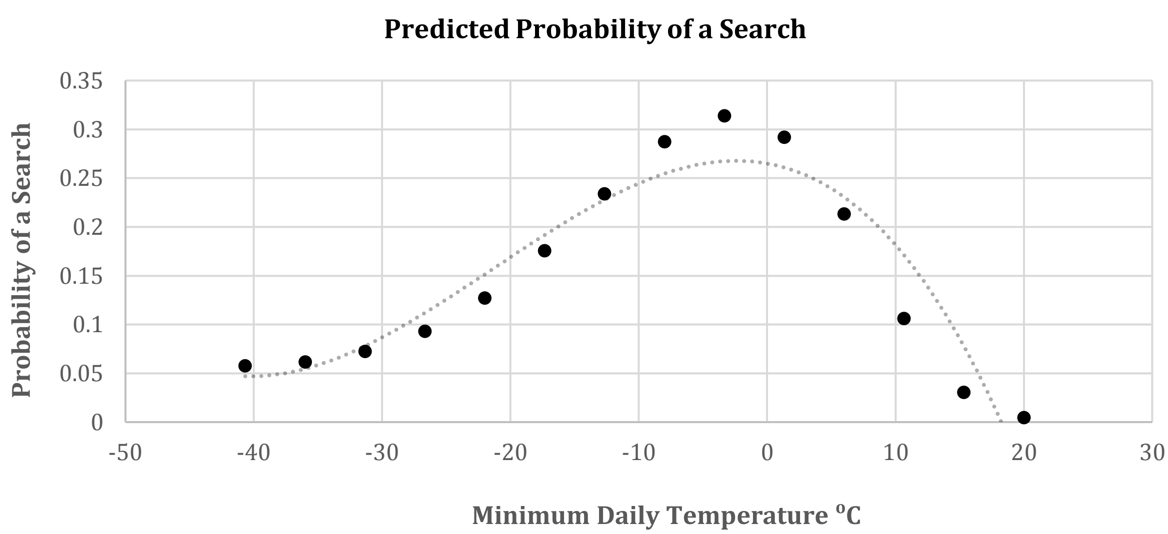

Figure 2: Predicted probability of a search and rescue case in Nunavut based on minimum daily temperature holding all other variables constant.

We conducted sensitivity analyses using a four-day moving average, top 5% cutoff for proxied control days, and using maximum or mean daily temp. The model results were robust to these changes and did not significantly differ.

Discussion

Land-use injury research in the Arctic has been limited by a lack of land-use data or inability to assess risk exposure, relying instead on descriptive statistics of injury events. Addressing this gap, we proxied exposure of individuals to potential hazards using gasoline sales. This approach allowed for analysis of associations between SAR events and environmental conditions. Thus, results denote when and under what conditions land-users are at the greatest risk of injury in the Arctic, informing injury prevention and treatment planning.

Most of the SAR incidents with a noted cause were related to mechanical breakdown or running out of fuel. However, most of the literature surrounding land-use injury in Nunavut discusses safety on the ice. This leaves leading causes of mechanical breakdowns or running out of fuel largely unexplored and thus potentially omitted by prevention programs.

In comparison to falling through the ice, mechanical breakdowns and running out of gasoline are likely influenced more by social factors and machine integrity [29]. In this light, effective interventions may consist of targeted education. For example, promoting use of satellite beacons, encouraging indigenous knowledge transfer, and highlighting the importance of equipment operability. Falling through the ice is often a more acute emergency than running out of fuel, being stuck, or having a machine breakdown, and may require prehospital and hospital emergency care. It is more common however, that individuals simply need timely rescuing and little to no emergency medical treatment if they are recovered swiftly. This highlights a need for a public health emphasis on bolstering SAR operations coupled with encouraging safe land practices.

Both temperature and ice conditions are predictive of the probability of a search and rescue taking place on a given day. As daily minimum temperatures nears -3^{o}C there is a greater chance of a SAR event. Mechanical breakdown and overheating, probability of being stuck in the mud or by ice floes, risk associated with high inland streams and falls through the ice have been reported to be higher during the spring and fall than in winter [14]. Ice conditions were also predictive of SAR incidents. As daily temperatures increase in the spring, ice thickness begins to decrease and the variety of ice types decreases. This pattern had negative correlations with SAR. Similarly, ice does not begin to thicken until after the fall SAR peak, correlating with more snow on the land and better operating conditions for machines. Ice concentration however generally decrease later, after the spring and fall SAR peaks, reflected by the positive correlation with SAR.

As with any proxy, the use of gasoline sales to simulate land-use has limitations. Gasoline sales were restricted to those ≤ 50 liters; however, buyers could have used the gasoline for any purpose. Furthermore, some buyers may have purchased gasoline numerous days or weeks before using it. This would have created a longer lag than accounted for. Some machines are more efficient than others, while snowmobiles, ATVs, and boats all consume gasoline at different rates. A land-use proxy that was able to estimate the kilometers driven or time on the land would be more accurate and precise. However, there are currently few alternate methods or tools to estimate land-use intensity in the Canadian north. In our development of this proxy approach, we validated the thresholds, temporal trends, and conceptual method through interviews with community members in multiple communities. The study was further limited by quality of SAR data. Event cause was often not reported, restricting analysis based on the type of land-use. Additionally, we were unable to examine trends at the community level because of the small number of cases in some locations.

In developing a method to quantify exposure to hazards and risk of injury, we demonstrate that weather and ice conditions may influence Inuit safety while hunting and traveling in the Arctic.

Given the limited medical care and health promotion resources across much of the North, efficient health care is essential. By highlighting when and under what conditions injury risk increases in Northern communities, nurses, physicians, and public health workers can anticipate and prepare. Response may include: 1) increasing prevention efforts during the highlighted high risk periods (mid-spring and fall); 2) ensuring adequacy of SAR operation resources during high risk periods; 3) preparing for higher likelihood of land traumas through review of medical protocols and continuing education. Based on the temporal lens, this study examines weather events. While more research is needed to understand climate implications, projected environmental change may further influence risk of injury on the land by elongating or shifting the high risk windows, and may be catalyzed amidst adaptation barriers in the region.[7, 13, 30] In this light, the public health field should prepare for potentially higher rates of SAR and land-based injuries in the Arctic.

Author Statements

Ethical approvals

Ethical approval was obtained from the Ethics Review Board of McGill University and from the Nunavut Research Institute.

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Competing interests

None declared.

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