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ORIGINAL ARTICLE

Community vulnerability to changes in the winter road viability and longevity in the western James Bay region of Ontario's Far North

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Abstract

A network of winter roads that consists of snow-ice roads over land, muskeg, and frozen lakes and rivers has been and continues to be a critical seasonal lifeline in remote-northern First Nation (FN) communities in Ontario's Far North. This study examines current vulnerability of the Fort Albany community to physical, social, and economic impacts associated with the changing of the viability and longevity of winter roads and its seasons, as well as the river ice regimes. Semi-directive interviews with key informants ($n = 8$) and structured surveys with winter road users ($n = 54$) were conducted to gather local knowledge about the evolution of winter roads and climatic and environmental changes in winter road conditions and seasons. Trends in the river ice breakup and flood events for the Moose River, Albany River, and Attawapiskat River were also examined. The results of this study indicate that climatic factors, particularly air temperature and snowfall, have directly affected the construction and maintenance of the James Bay Winter Road. Trend analyses of spring flooding for the three rivers exhibit statistically significant increases ($p \leq 0.01$) over the past few decades; thus, flooding in nearby communities has become a more significant threat in recent years. A few short- and medium-term adaptation strategies have been initiated in response to the impacts of climate change on winter roads; however, developing long-term planning and feasible adaptation for remote-northern communities in Ontario's Far North is necessary.

Keywords Climate change · First Nations · James Bay · River ice · Vulnerability · Winter roads

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Introduction

Winter roads provide critical transportation routes in northern Canada. Winter roads can be defined as any type of roads made of snow and/or ice that remain functional during the winter months (Adam 1978). Since the 1950s, seasonal networks of winter roads—that sometimes link to all-weather road system—were implemented in remote-northern communities in Canada (Prowse et al. 2009). In 1999, the Government of Ontario spent $2.7 million to construct and maintain over 2700 km of winter roads in Ontario's Far North; in 2015–2016, they invested $5.0 million for the 3160-km winter road system connecting 31 remote-northern communities to a highway or railway system (Dore and Burton 2001; Government of Ontario 2016). Ontario's Far North, as defined by the Far North Act, 2010, refers to the northern portion of Ontario that covers 42% of the province's land mass (Government of Ontario 2015). The winter road network in Ontario's Far North operates for 3 months each year (i.e., January–March) over the past 30 years and is integral in providing access to major goods to most communities in the region (Chiotti and Lavender 2008). In addition to economic benefits, these corridors also facilitate social connections among nearby remote-northern communities (Chiotti and Lavender 2008; Furgal and Prowse 2008).

The seasonal length of the winter roads depends on particular climatic factors, such as surface air temperature, precipitation, snowfall, and wind. These climatic conditions also influence the initial ice development that includes ice freeze-up, growth, and thickness before road construction begins (ACIA 2005; Knowland et al. 2010; Hori et al. 2015). The implications of climate change to the winter road system are of concern. In recent years, an increase in mean air temperature has been observed at higher northern latitudes by both instrumental records and Indigenous observations (Ford et al. 2006; Furgal and Prowse 2008). With an increase in mean temperatures, there has been increasing concerns with delayed opening dates of the winter roads and a decline in the quality of the roads (ACIA 2005; Chiotti and Lavender 2008; Furgal and Prowse 2008; Tam et al. 2013; Hori et al. 2015).

As reported by Hori et al. (2015), ice thicknesses of freshwater waterways including rivers and muskeg in the western James Bay region have been artificially enhanced. Winter roads in the region run through large estuaries of three major rivers so that ice bridges are required. Surface flooding and spray-ice techniques have been commonly used, to maximize the ice thickness of ice bridges (Prowse et al. 2009); thus, these methods artificially increase ice thickness of winter roads in the region. An increase in temperature not only affects the winter road system directly but may also impact other environmental phenomena, such as spring floods and ice jams (Chiotti and Lavender 2008). Communities of the western James Bay region are located on flood plains; as a result, they have been affected by a number of spring floods in the past (Chiotti and Lavender 2008; McCarthy et al. 2011). An increase in the magnitude and frequency of spring floods has been observed in recent years, increasing the risk of flood damage to these communities (McCarthy et al. 2011).

Changes in river ice freeze-up and breakup trends are also complex (Ho et al. 2005; Beltaos and Prowse 2009). Ho et al. (2005) reported that no traditional river ice breakup occurred in 1999–2002 for the Moose River, Albany River, and Attawapiskat River in the western James Bay region due to breakup changes being too gradual to measure. In 2004, however, a major breakup event in Attawapiskat caused severe floods, forcing a full community evacuation (Ho et al. 2005).

The remote-northern First Nation (FN) communities in Ontario's Far North are particularly vulnerable to climate variability and climate change. However, there remain significant knowledge gaps regarding the vulnerability of these communities to climate change (Chiotti and Lavender 2008; Tam et al. 2013). Therefore, the main objective of this study was to explore the vulnerability of James Bay Cree communities (i.e., physical, social, and economic impacts) to changes in the winter roads. Also, trends in river ice breakup and flooding were examined with links to the current maintenance practices with respect to winter roads. An understanding of the impacts of climate change on the winter road system is of particular importance to the FN communities in the Hudson-James Bay region due to the potential impacts on everyday life.

Study area and community

The western James Bay region of Ontario's Far North is classified as having a subarctic climate, which typically includes short and cool summers and long and cold dry winters (Hori et al. 2012). The James Bay Winter Road (JBWR) runs through several rivers, streams, and muskeg areas across the western James Bay coast (Fig. 1). In the Hudson Bay Lowlands, approximately 80% of the region consists of muskeg or peat-forming wetlands (Adam 1978).

The winter road network spans 320 km in length along the coastline of the Hudson-James Bay (Government of Ontario 2016). During the winter season, the winter road connects the coastal and remote communities of Attawapiskat, Kashechewan, Fort Albany, and Moose Factory to the town of Moosonee, which is the northern terminus of the railway in the region. The JBWR is currently operated and maintained by the Kimesskanemenow Corporation (K-Corp.), owned by the FN communities of Attawapiskat, Kashechewan, Fort Albany, and Moose Cree (Kimesskanemenow Corporation 2015). The name *Kimesskanemenow* is a Cree word, which means "our road."

Fort Albany FN, the focus community of this study, has a total population of approximately 850 Cree (McCarthy et al. 2011). Fort Albany FN was chosen among remote communities of the western James Bay region, because it is approximately midway on the JBWR, and our research team has long-standing ties to the community.

Methodology

Vulnerability framework

The IPCC (2007) defines vulnerability as "a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" (p. 21). In order to analyze community vulnerability and adaptability to climate change, Ford and Smit (2004) developed an analytical framework for vulnerability analysis. They conceptualized vulnerability as a function of exposure sensitivity and adaptability to deal with climatic stresses (Ford and Smit 2004). Exposure sensitivity reflects the susceptibility of people to climate-related risks that include those associated with climate change (Ford et al. 2006). This vulnerability

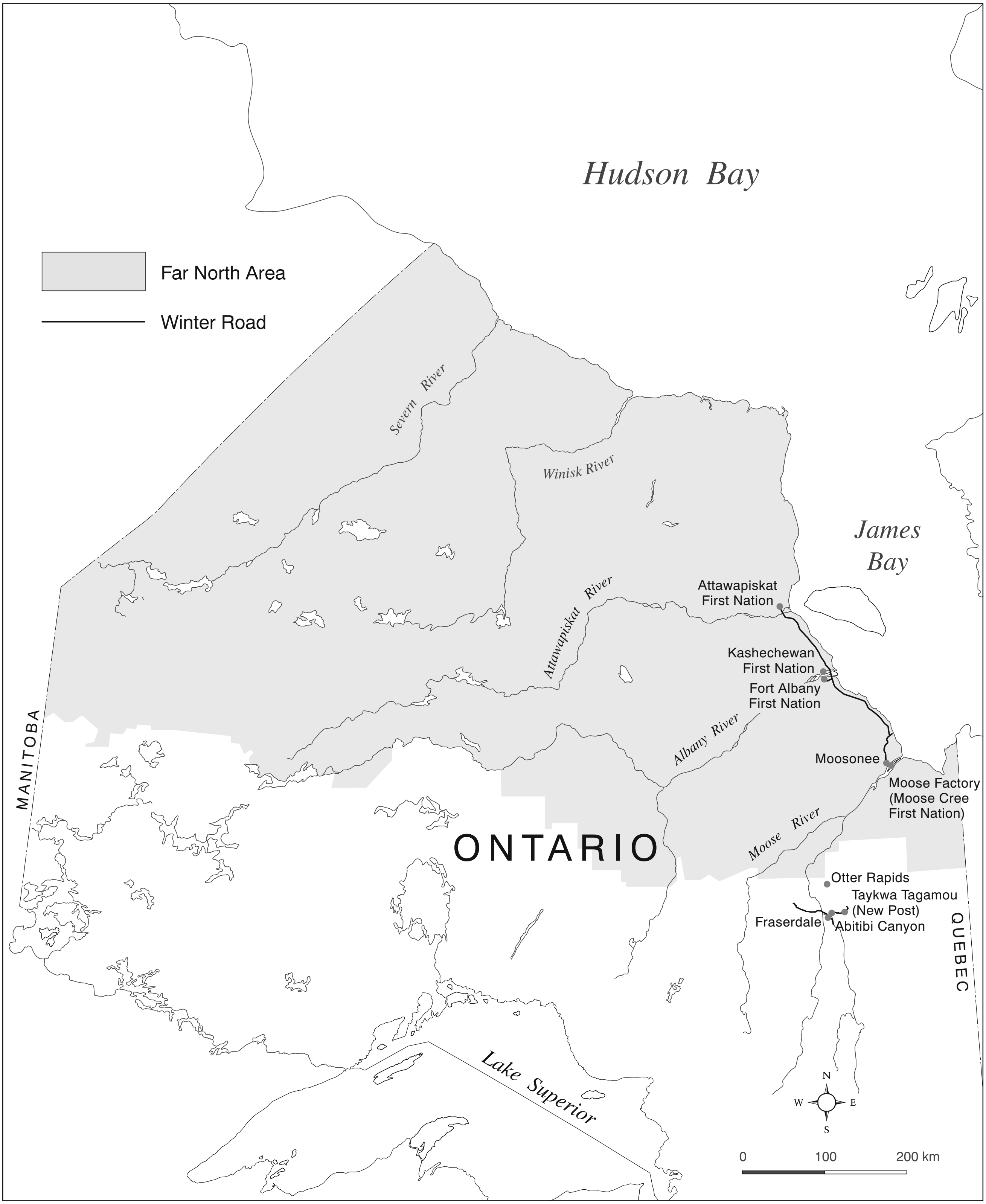

Fig. 1 Map of Ontario's Far North, including the FN communities, the town of Moosonee, and the James Bay Winter Road

framework and conceptualization were employed in a number of case studies of climate change involving Indigenous communities in Canada's Arctic and subarctic (e.g., Ford et al. 2010). These case studies indicate that many

Indigenous communities demonstrate significant adaptability to cope with past and present environmental changes, although they are often more vulnerable to such changes due to not only their strong relationship with the environment but also ongoing socioeconomic changes that are rooted in colonial history, historic inequity, land dispossession, and globalization (Ford et al. 2015; Pearce et al. 2015). There are emerging vulnerabilities that are driven by ongoing societal and environmental changes (Ford et al. 2015). The vulnerability framework provides an essential starting point for understanding the complexities of Indigenous vulnerabilities. Thus, this study utilizes the aforementioned model of vulnerability to assess current vulnerability and adaptability of the Fort Albany community to the changes of winter road system and river ice regimes.

Methods

River ice breakup data

River ice breakup data for the three major rivers (the Moose River, Albany River, and Attawapiskat River) of the western James Bay region were used to examine the temporal trends of river ice patterns of the region and the links to the current practices of winter road construction and maintenance. The method to determine breakup dates for the Moose River and the Attawapiskat River was determined by a marking stick, which is inserted into the river ice during winter, and the marking stick falls when the river ice begins to melt and break in spring (Ho et al. 2005). Historically, the breakup dates for the Albany River were determined by the date that the causeway joining Sinclair Island to the mainland was washed away (or water/ice entered the channel) in spring (Ho et al. 2005), and more recently through direct observation (e.g., helicopter) up-river of actual ice breakup. Breakup data for each of the three rivers were obtained from the Ministry of Natural Resources and Forestry for the period 1950–2014. The data also indicated major flood events in each river.

River ice breakup data were analyzed by using the non-parametric Mann-Kendall correlation and the Theil-Sen method in order to identify any statistically significant trends between year and date of breakup. These statistical techniques are typically used in sea ice studies (ice freeze-up and breakup dates) of the Hudson Bay region by Gagnon and Gough (2005, 2006) since time series trends are not necessarily linear. The Mann-Kendall test determines the statistical significance of the trends at a selected significance level (Helsel and Hirsch 2002); thus, this study used $\alpha = 0.05$ for the test. The Mann-Kendall test, however, does not estimate the slope of a trend, so the Theil-Sen method was applied for this purpose. The Theil-Sen method is also non-parametric and provides a more robust estimate of a slope than the methods of least-squares, since the median of the sets of slopes is less affected by outliers or gross errors in the time series (Sen 1968).

In order to examine the relationship between year and flood event, Pearson's product-moment correlation coefficient (Pearson's r) was performed. The Student's t test statistic was used to determine the statistical significance of Pearson's r at the 95% confidence level.

Interviews with key informants

Semi-directive interviews were conducted with eight key informants in February 2015. The eight key informants were from three FN communities and a non-FN individual (Moose Cree FN = 2, Fort Albany FN = 4, Kashechewan FN = 1, and non-FN = 1). The key informants were all male, and they were between the ages of 31 to 78 years old (mean = 50). The key informants were purposively recruited based on their knowledge and experience with the construction and maintenance of JBWR. Specifically, former/current managers and employers of JBWR were recruited as the key informants. The aim of the key informant interviews was to understand how the winter road system has evolved with changing climatic and environmental conditions, as well as to document past and current practices for construction and maintenance of the JBWR. Moreover, collecting local knowledge and observations of the winter roads provides insight into intricate environmental changes not necessarily found in instrumental data. The community-based research coordinator helped in identifying, contacting, and recruiting participants to interview for this study. All interviews were conducted in English although a Cree interpreter was available upon request. Interviews lasted from 20 to 60 min and were conducted at a convenient location and time for the participants.

Winter road user survey

Fifty-four winter road user surveys with Fort Albany FN were conducted from February to April 2015. The majority of winter road users were male ($n = 38$ (70%)). The ages of the winter road users ranged from 18 to 69 years old (mean = 35). The winter road users were purposively selected from a household list of Fort Albany by the community-based research coordinator who was a Band member and had lived there for more than 30 years. One eligible person was invited to participate per household. Eligibility criteria for the community members were as follows: (1) the participant must be self-identified as Indigenous, ≥ 18 years old; (2) the participant must have been living in Fort Albany for the majority of their life; (3) the participant must currently reside in their community at the time of the survey; and (4) the participant is a main driver in his/her household. The winter road user survey response rate was 77% (or 54 of 70 eligible households). The aim of the winter road user surveys was to examine exposure sensitivity and adaptive capacity of the Fort Albany community, including winter weather and climate, ice and water conditions, winter road use and its conditions, and spring flooding. The survey consisted of 28 questions divided into seven sections. Written consent (informed) was obtained from each participant after being informed of the purpose of the study. Ethical approval for the study was obtained through the University of Toronto Research Ethics Board.

Data analysis for the interviews and surveys

Key informant interviews and open-ended survey responses were recorded by hand and a voice recorder (only for those who provided participant approval), and records were transcribed verbatim. Qualitative data were then analyzed using QSR NVivo (version 10). A thematic content analysis has commonly been performed on interview data to identify common groups or categories relating to environmental and human impacts in northern communities (e.g., Furgal and Seguin 2006; Tam et al. 2013). Thus, this study employed a thematic analysis approach to identify themes or patterns from the interview transcriptions and open-ended survey responses. Descriptive statistics were used to analyze the closed-ended survey responses and the most frequently occurring words and concepts in open-ended survey responses.

Results

The vulnerability framework was used to understand and present a characterization of how changes in winter road system and river ice regimes were experienced by community members. Community exposure sensitivity and adaptability are evident in the winter roads and river ice conditions.

Exposure sensitivity

River ice breakup and flood event trends

Statistical trend analyses of river ice breakup and major flood events (1950–2014) for the Moose River, Albany River, and Attawapiskat River are provided in Table 1. Trend analyses revealed that only the Moose River has shown a noticeable trend ($p \leq 0.1$) toward an earlier breakup, although the trend is small according to the Theil-Sen slope (− 0.08 days per year).

The flooding data for the three rivers revealed that flooding events have exhibited statistically significant correlations between major flooding events and time. The Moose River and Attawapiskat River showed a statistically significant increasing ($p \leq 0.001$) trend. Similarly, the Albany River indicated a statistically significant increasing ($p \leq 0.01$) trend over time.

Past and current practices of the winter road construction and maintenance

Until the 1950s, the communities in the western James Bay region were only accessible by boat during the summer season and by a dog sled team during the winter season (Laguerrie 1994). In the early 1950s, the JBWR was first built for the construction of the Mid-Canada Radar Line sites (McCarthy et al. 2010).

The majority of key informants indicated that the initial construction of the winter road was different from current practices of the JBWR. Snow on the winter road was first compacted by a tractor train with sleighs, which brought fuels and building supplies to the communities. Roman Catholic missionaries used to haul supplies up along the coastline of James Bay from Moosonee to Winisk, often referred to as "missionaries trail." The missionaries came into the communities with the first tractor train. Based on participants' accounts, the initial winter road was very narrow and the road quality was poor. As indicated, the winter roads were mainly built by compaction of snow using any available tractor, roller, and/or bulldozer. Such practices have changed since De Beers Canada Inc. started their mining project in the western James Bay region. Specifically, the Victor Diamond Mine, an open-pit diamond mine, is located approximately 90 km west of Attawapiskat (McCarthy et al. 2010). This mine construction commenced in 2006; as a result, a new section of the winter road was built to connect Attawapiskat to the mine site (McCarthy et al. 2010).

For the last 10 years, the construction of the winter road typically began in early December (Kimesskanemenow Corporation 2015). Under the management of K-Corp., the JBWR is divided by four sections to construct and maintain the road and the four FN communities of Attawapiskat, Kashechewan, Fort Albany, and Moose Cree take responsibility for each section (K-Corp., pers. comm. 2015). The JBWR construction on frozen lakes, rivers, smaller waterways, and open muskeg starts with initial compacting of snow for frost penetration, typically starting when the snow depth reaches about knee height (K-Corp., pers. comm. 2015). In each section of the road, about 5–10 snowmobiles are used to compact the snow, which reduces its insulating effects and promotes deeper frost penetration (K-Corp., pers. comm. 2015). Once the ice thickness reaches approximately 15–25 cm in the muskeg and approximately 25–30 cm for lakes and rivers (Adam 1978; Campbell and Bergeron 2012), a small- and/or medium-sized bulldozer is used to plow the snow and drag tires to smooth and strengthen the surface (K-Corp., pers. comm. 2015). In order to increase the durability of the road that can support full loads, surface flooding is done by a water truck to create an ice cap on top of the road surface (K-Corp., pers. comm. 2015). Creek and stream crossings are also filled with snow and flooded, creating a ramp between land and water

Table 1 Average river ice breakup dates, the Mann-Kendall (MK) test, and the Theil-Sen (TS) slopes (days/year), as well as the Pearson correlation coefficients for the major flooding events during 1950–2014

	River ice breakup			Major flooding
	Average breakup date	MK	TS slope	*R* value
Moose River	April 29	$-0.144^{\bullet}$	−0.08	0.430^{***}
Albany River	May 1	−0.087	−0.06	0.365^{**}
Attawapiskat River	May 4	0.112	0.07	0.400^{***}

$^{\bullet}$ < 0.1

* < 0.05

** < 0.01

*** < 0.001

(INAC 2010; K-Corp., pers. comm. 2015). For ice bridges across major rivers, the minimum ice thickness for a full weight (GVW 55,000 kg) is at least 1.09 m (43 in.) with a road width of 30–60 m (100–200 ft) (Adam 1978; K-Corp., pers. comm. 2015). Testing and measuring ice thickness during construction and maintenance of winter road are recorded regularly until the official road closure at the end of March (K-Corp., pers. comm. 2015).

Importance of climatic indicators for the winter road

The majority of key informants noted the importance of air temperature and snowfall for the construction and maintenance of the JBWR. Many noted that it is important to have very cold temperatures before and during the construction period. As one key informant stated:

> We get around anything under double digits, really cold like − 20 to – 40 °C. That range … is good for the road. Colder the start is better because first we have to run 10 snowmobile machines to pack the snow down, so water comes up and then frost starts going down. The machines go on top, so they won't fall through. That is what we do the first. (Participant #1).

This observation coincides with past findings that the freezing degree-days during the month of October through to December (preconditioning period of the winter road) play a key role in providing a more climatically favorable construction period and earlier opening dates (Hori et al. 2015). Knowland et al. (2010) reported a critical temperature threshold for flooding ice bridges at Norman Wells, Northwest Territories—5 cm of water will freeze successfully overnight at a daily mean temperature of − 18 °C and 9 cm will freeze overnight with a daily mean temperature of − 31 °C or lower. Although none of the key informants indicated any required temperature thresholds for constructing ice bridges, one key informant indicated, "the ideal situation is quick freeze" (Participant #2).

Second, many participants noted that there should be sufficient snow cover to pack the snow and build creek and stream crossings. One key informant stated that "with snow, again, you want some snow but not too much, so you want minimum snow during the ice construction" (Participant #2). At least 10 cm of the packed snow is required on the winter road surface in order to maintain a high albedo, as well as to protect the ground surface from tracks and vehicles (INAC 2010; Knowland et al. 2010). If there is heavy snow cover on the ice before the construction period, it may cause unsafe ice conditions throughout the winter road season (Knowland et al. 2010). Another key informant described how snow affects the rate of ice growth: "… we look at how [it] freezes, [if] the lots snow in December, be very thin, [if] no snow in December, be thick because [of] cold, snow is blanket and insulated" (Participant #1). Therefore, the air temperature and snowfall indicate the importance of climatic factors in shaping exposure sensitivity to climate-related risks for the construction and maintenance of the JBWR. In fact, warmer temperatures and insufficient snowfall increase exposure sensitivity to climatic risks for the winter roads.

Other climatic indicators, such as wind speed and direction may alter natural ice growth of the winter road. For instance, ice grows faster if wind is able to blow snow cover off the frozen water surface to reduce its insulating effects (Williams and Stefan 2006). The moon and tides may also alter natural ice formation and growth. Two key informants indicated that major river crossings are affected by the tidal currents, because the tides can cause ice to rise and/or fall. Also, one key informant noted their perception on the association between moon activity and weather:

> Sometimes [when it's] warm, water comes up from the bottom, like slush ice in muskeg, water comes

> out, we get stuck on the winter road. December, sometimes in January, very warm sometimes. Maybe the moon does that, getting full moon, water comes, lots slush (Participant #7).

The correlations between climate variations and lunar cycles are of interest to scientists; however, such mechanisms have been unclear (Royer 1993).

Current practices of winter road use

The JBWR has become a critical route connecting remote communities in the western James Bay region. Key informants stated that it used to be only driven by snowmobiles and by small trucks at times, on the winter road approximately 20 years ago. Today, all types of vehicles, from a small passenger car to a large transport truck, travel across the winter road. Based on key informants' accounts, approximately 30–50 vehicles travel on the winter road per day, though this tends to increase on weekends and social events. Key informants also mentioned that the numbers of pickup trucks, in particular, have increased rapidly:

> We didn't have enough vehicles long time ago in this town, nobody hardly using any pickup trucks to go to Moosonee, roads are too soft, lots of snow, sometimes they fall, they stuck, so they didn't use those. It wasn't meant for vehicles back then, just getting supplies then. Gas, fuels, groceries, lumber, that's why we were doing that, just building that road all the way to Moosonee, get that train loaded it up come back with full loads, that's it. Now I noticed that when we worked here we can use pickup trucks come back home do it again every day (Participant #5).

For winter road users in Fort Albany, the majority (76%) of respondents indicated that they use the winter road a few times during the winter road season. Almost half (48%) of winter road users drive on the winter road in the morning due to better road conditions (i.e., easy to travel, colder in the morning, and stable ice) and purchase groceries and necessary supplies at the local stores in Moosonee.

The results of descriptive statistics of current winter road use are summarized in Table S1 in the Online Resource. The winter road users in Fort Albany described the JBWR as an important social lifeline (i.e., visit family and friends). In addition, 93% of winter road users reported that the JBWR is important to them due to financial (i.e., cheaper to travel) and mental health (i.e., feel less isolated) reasons. These responses are consistent with past research reporting the impact of changes in cold weather, ice conditions, winter roads and trails, and wildlife on five FN communities in northern Manitoba (CIER 2006). For example, community members indicated that the winter roads, access trails, and frozen water bodies play a vital sociocultural role in their communities. A shorter winter road season and increase in unreliable road conditions decreased opportunities to participate in sociocultural activities, as well as to travel outside of the community, while also increasing financial costs, feelings of social isolation, and accidents along the winter roads and/or trails. Such economic, social, and cultural stresses due to a shorter winter road season increase exposure sensitivity to the winter road users in Fort Albany.

Changes in winter road seasons and conditions

The majority of key informants and winter road users described the effects of warming on construction and maintenance of the winter road and its seasons and conditions over time. One key informant stated that a long time ago, winter temperatures were about − 50 and − 60 °C in December. Today, most key informants and winter road users (85%) reported that the winter weather as being warmer now compared to the past. Moreover, 60–70% of winter road users felt that air temperature, rain, and snow have shown a marked change in recent years, such as an increase in rain during the winter season. Key informants believe that snowfall has decreased; however, winter road users have found that there has been an increase in snowfall over the recent years.

The effects of warming have been observed in the timing and quality of ice freeze in the water bodies (e.g., lakes, rivers, creeks, and muskegs), before and during the construction period. For example, water used to freeze early before snowfalls, water in rivers and lakes do not freeze to the same extent as before, and/or ice in muskeg is too thin. One key informant expressed concerns about the ice of the road when flooding, because of such unstable ice freeze conditions:

> You see when it freezing and flooding on top, when you need to freeze because sometimes it won't freeze enough and get the shell ice and you get pockets of water, then in the end just going back. What has been doing lately, it will freeze and break up, stop, freeze, so when we make a road, when we drill, there's a pocket of air and a pocket of water in that ice (Participant #1).

Almost half (47%) of winter road users also noticed changes in coastlines, rivers, and muskeg due to changes in winter climate. These observations include more water and slush in coastlines and rivers, thinner ice in rivers and muskeg, and partially frozen in some areas. In particular, changes in the timing of river ice freeze and melt have been observed by the majority (70%) of winter road users. These observations include that the river freezes later or not completely or not at all, river ice melts faster, and river ice breakups earlier. This is consistent with past research findings that have found delayed freezing of water bodies and decreased ice thickness (McDonald et al. 1997; Ho et al. 2005; CIER 2006; Tam et al. 2013). CIER (2006) reported that the construction of winter roads in northern Manitoba was delayed due to late ice freeze-up, weaker ice, and thinner ice in some muskeg areas. The majority (65%) of winter road users also stated that the timing of the freezing and melting cycles is harder to predict now due to warmer, different, and/or unpredictable weather. Cree elders from the western James Bay region have noticed that the timing of river ice freeze has been delayed in recent years so that the prediction of the river ice freeze/thaw cycles has become more difficult (Ho et al. 2005). The majority (78%) of winter road users reported that spring melt has changed in recent years, such as earlier thaw, melt, and breakup due to warmer springs. This is consistent with local observations in 2003 and 2010 that spring melt occurred earlier with infrequent traditional river ice breakup (Ho et al. 2005; Tam et al. 2013). Many winter road users (81%) also reported that spring flooding is an issue in the Fort Albany community, and they commented that warming may lead to more snow, earlier and quicker spring melts, and/or ice jams.

Three key informants reported changes in the strength, frequency, and severity of wind and snowstorm during the construction and operation periods. As they mentioned:

> Wind gets weaker too over the years, not like a long years ago, I couldn't see hundred of miles because it's blown snow, can't see. I've never seen those kinds of storms anymore, just weak storms [now] (Participant #5)
>
> One week, sometimes you can't go − Stormy. Now is different. Storm now is just a day. Storm today, you can probably go out tomorrow because we get better machines today, clear the road, but before, we have nothing, we [only] have a tractor, [it] took longer to maintain the road. Storms last longer too, [and] more snow too … Storms are affecting everything in the past, even if train tracks. Train came once a week before, now everyday now (Participant #3)
>
> Lately, we have not gotten snowstorms until March. Normally, we [are] getting in December, or January, or February … I remember 5 years ago, we closed for one week because it stormed for 3 days. We used lots machines, day and night 24/7 to get it open, took 3 days to get it open (Participant #1).

Changes in wind patterns have been observed in the Hudson-James Bay region by local observations (McDonald et al. 1997). Two winter road users in Fort Albany indicated that blizzards used to be more intense, but now, they are weaker and occur later in the winter season (e.g., March). This supports local observations that snowstorms and blizzards are now less frequent in some communities in northern Manitoba (CIER 2006).

The majority (65%) of winter road users stated that such changes in air temperature, ice freeze, and wind have affected the winter road, resulting in shorter winter road seasons and unstable ice conditions. Many respondents (74%) indicated that the winter road seasons and its conditions have changed due to the effects of climate change. Changes in the winter road conditions have been observed by winter road users in recent years (Table 2). As shown in Table 2, an average of 59% of respondents observed changes in the winter road conditions, while 22% of respondents answered "don't know" for all items that were on the list. These respondents were relatively young (18 to 33 years old) and the majority of them were female (male = 4; female = 8). All of these respondents used the winter road only once or twice during the season. Thus, factors such as gender, age, and experience result in knowledge gaps related to winter roads and impact exposure sensitivity of winter road users.

Changes in the length and timing of the winter road season have also been reported by the four key informants. They stated that the opening dates of winter roads in the past were earlier than now because of colder temperature and more snowfall; however, the roads were of lower quality due to the relatively simple construction techniques used. Also, the closing dates of the winter road were later in the past. Although the winter road users have noticed changes in the winter road conditions, only 26% of winter road users have noticed changes in the reliability of winter road. This may be because the current JBWR has been constructed and maintained with modern technology and techniques that enhance road quality, durability, and ice thickness.

Adaptive capacity

When the length of the winter road season is shortened due to the effects of warming, 50% of winter road users commented that there would be less necessities and building supplies available in the community, leading to increased costs. However, the Fort Albany community members demonstrate some capacity to adapt to changes in the winter road seasons and conditions. The majority (81%) of winter road users indicated that they would be able to adapt to such shorter winter road seasons: 61% of respondents indicated that they would use alternate travel options, such as air charter and snowmobile and/or barge during the ice-free seasons although some noted that these alternatives are expensive. Tam et al. (2013) reported that shipping goods by air or barge is more costly than using ground transportation.

Key informants identified some adaptation strategies that are now being used to address unstable winter road conditions and a shorter winter road season due to the implications of climate change. Currently, taking winter road safety training is

Table 2 Observations of the winter road users for changes in the winter road conditions

Items	Response (*n* = 54 (%))			
	Agree	Neither agree nor disagree	Disagree	Don't know
Shorter winter road season	36 (67)	2 (4)	4 (7)	12 (22)
Delayed winter road season	33 (61)	3 (6)	5 (9)	13 (24)
More earth patches/potholes	33 (61)	2 (4)	3 (6)	16 (30)
More white ice (or weaker ice) on the road	30 (56)	2 (4)	4 (7)	18 (33)
Increased slush on the road	29 (54)	3 (6)	6 (11)	16 (30)
Thinner and weaker ice (or less blue ice) on the road	29 (54)	2 (4)	6 (11)	17 (31)

mandatory for all winter road construction and maintenance workers. As one key informant mentioned, "there is a very high standard for safety on the road" (Participant #2). At present, safety is of fundamental importance when working on the winter road. Historically, two key informants said that there was no such training and/or orientation for workers approximately 20 years ago.

An increase in funding in order to meet the need of construction and maintenance costs can increase the usability and durability of the winter roads. One key informant stated that:

> For the construction time, of course, there is the variance you need the colder, and just a right amounts of snow makes a big difference, but on average the construction is governed by the amounts of money had been spent to do the actual [construction], you know, creeks … initial compaction so on, you know, the more money they have and spend, you know, what I mean, the fast they get the road ready … (Participant #2).

For the JBWR, not only the Government of Ontario but also De Beers Canada Inc. has provided funding due to the Victor Diamond Mine that needs to use the JBWR for transporting heavy equipment and machinery from Moosonee.

Developing alternative winter road routes in order to avoid certain creeks and installing permanent bridges on James Bay have also been discussed previously; however, these may create potential negative environmental impacts. Transportation alternatives, all-weather roads in particular, have long been considered among the FN communities. The Mushkegowuk Tribal Council has examined the feasibility of an all-weather road to link the western James Bay communities with the Ontario Highway 11 (Mushkegowuk Council 2015). Although the costs of constructing and maintaining all-weather roads are considerably more expensive (Dore and Burton 2001), as well as the risk of significant disturbance to the natural environment (Ontario Ministry of Natural Resources 1990), nevertheless, almost half (46%) of winter road users indicated that all-weather roads may bring socio-economic opportunities into the community. By contrast, an airship (also known as blimp or dirigible), which is one of the transportation alternatives, has less environmental impacts and more economically potentials compared with conventional air transportation (Prentice and Turriff 2002; CIER 2006). One key informant asserted that:

> It will be so much easier in the environment − number one, and it will great cost saving to the people who reside in the northern communities. Their cost of livings is horrendous, you know. It would certainly I think that is the way to go, airships (Participant#2).

Discussion and conclusion

The main objective of this study was to explore and characterize the vulnerability of James Bay Cree communities to changes in the winter road system, particularly the impacts of climate change on the winter roads. This study shows that trend analyses of flooding events for the Moose River, Albany River, and Attawapiskat River exhibit statistically significant increases over time; thus, major flooding in nearby communities has posed an imminent threat in recent years. As aforementioned, the JBWR runs through several rivers and muskeg so that river and creek crossings are enhanced to cross these areas. Thus, the ice thickness of freshwater waterways in the region has been artificially increased. This may be an indication that not only increased warming, but also artificially increased ice thickness of waterways is potentially contributing to the increased intensity and frequency of spring flooding observed in recent years. Most winter road users indicate that spring flooding is an issue in Fort Albany; however, only a few of them report that the ice is thicker than before and such thickness may also cause flooding when it melts.

The results of this study indicate that the construction and maintenance of the winter roads have been directly affected by climatic factors, in particular, air temperature and snowfall. Thus, increased warming will significantly impact current practices related to winter road construction and maintenance, as well as winter road use. Such climatic stress increases vulnerability to the winter road system and the winter road users in Fort Albany and other FN communities. Changes in winter road seasons and conditions due to the effects of warming as a consequence of climate change will become the norm in the western James Bay region. The local observations of warming weather align with past studies addressing how the Fort Albany community has been affected by changing climatic conditions (Ho et al. 2005; Hori et al. 2012; Tam et al. 2013). An increase in monthly mean temperatures has been observed in the western James Bay region by instrumental records and Indigenous observations (Gagnon and Gough 2005; Hori et al. 2012; Tam et al. 2013; Hori et al. 2015). Hori et al. (2015) reported that statistically significant warming trends in air temperatures ($p < 0.05$) were observed from January to April for the period 1961–2014. Historical temperature data in regions over Hudson Bay and the Canadian Arctic also indicated statistically significant warming during the winter and spring months, and similar local observations were made in northern Manitoba and some regions in the Canadian Arctic (Gagnon and Gough 2005; CIER 2006; Laidler et al. 2009; Statham et al. 2014).

Changes in the length of the winter road season and its conditions have been reported by the participants in the present study. In the 1970s and 1980s, the average opening date of winter roads was around late December to January 1 (Kataquapit 2012; Moosonee Transportation Limited, pers. comm. 2015), while the average opening date for the last 10 years is January 16 (Hori et al. 2015). It should be noted that the opening dates for the last decade were for light traffic (GVW 7500 kg), and the process of ice-capping was continued until the road could support full weight (GVW 55,000 kg). Public access has been allowed before and after the JBWR officially opens and closes; however, the road has been designated "drive at your own risk." Although enhancing the ice thickness of the winter road increases its load-bearing capacity, the impact of the extra thickness of ice on melting events is still unknown and of concern.

This study appears to reaffirm the adaptability of the Fort Albany FN community to the shorter winter road season. There is a sense of adaptability and resiliencies to the effects of climate change within the Cree communities of the western James Bay region (Lemelin et al. 2010; Tam et al. 2013). Because of their long history of resourceful adaptation to changing climatic and environmental conditions in their traditional homeland, many participants expressed confidence in their ability and strength to adapt to the effects of climate change on their traditional lifestyles (Lemelin et al. 2010; Tam et al. 2013). Vulnerability to climate change is inherently dynamic so that it varies among communities as well as among different groups within the communities (Ford et al. 2008). Those who rely on the winter road system, particularly young winter road users in Fort Albany, have a high level of exposure sensitivity. Future research should include working with other FN communities who are reliant on the JBWR to understand their risks to winter road changes, because local adaptability differs among communities. Climate change acts as a trigger on the root causes of vulnerability linked to marginalization, disempowerment, and colonization (Ford et al. 2015). Thus, understanding non-climatic drivers of vulnerability and constraints to adaptation is also an area for further work. Short-term, some adaptation strategies in response to the current climatic changes on winter roads have been incorporated into the road construction and maintenance protocol; however, a focus on long-term planning and adaptation is necessary to reduce vulnerability and enhance adaptability within the community. Suggestions from community members include construction of all-weather roads.

This study has provided greater insight on the effects of climate change on the winter road system, which is a critical seasonal lifeline in Ontario's Far North. In the western James Bay region, the JBWR has now become an important asset for not only providing a relatively inexpensive land transport of supplies but also facilitating social interactions during the winter season among remote communities. In summary, the results of this study help to inform public policy and decision-making processes addressing physical, social, and economic impacts associated with changing winter road longevity and river ice regimes.

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