How Permafrost Thaw May Impact Food Security of Jean Marie River First Nation, NWT

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ABSTRACT
The Jean Marie River First Nation (JMRFN) assembled a project team to exchange traditional, local and scientific knowledge to produce maps showing the vulnerability of traditional use areas near Jean Marie River to permafrost thaw. Landscape changes driven by permafrost thaw have and will have considerable impacts on country food. The vulnerability hazard map resulting from this project is tailored to the needs of the JMRFN community, is culturally oriented and, when overlain with spatial traditional land use information, brings a new, integrated perspective regarding climate change impacts on the JMRFN. This project represents a prototype for future surveys with mapping aimed at identifying and quantifying the impacts of permafrost degradation from a broader and more holistic viewpoint that combines western science and traditional and local knowledge.

RÉSUMÉ
La communauté de Jean Marie River et ses partenaires ont combiné et mis en commun leurs savoirs traditionnels, locaux, et scientifiques pour produire des cartes de vulnérabilité aux changements climatiques des aires utilisées pour leurs activités traditionnelles. Les changements du paysage provoqués par le dégel du pergélisol ont et auront des impacts considérables sur la nourriture issue du territoire. La carte de vulnérabilité aux risques de cette étude est taillée pour les besoins de la communauté, est orientée culturellement et, une fois recouverte par des informations spatiales sur l'usage traditionnel du territoire, apporte une nouvelle perspective intégrée sur l'impact des changements climatiques sur la communauté. Ce projet est le prototype des futures études et cartographies visant à identifier et quantifier les impacts de la dégradation du pergélisol d'un point de vue élargi et holistique combinant les sciences occidentales avec des connaissances traditionnelles et locales.

1 INTRODUCTION

The future impact of climate warming on communities and infrastructure is one of the most important issues in northern Canada. Many studies already have been conducted to quantify impacts of thawing permafrost on northern communities and their infrastructure in the context of changing climate (Allard et al., 2007a, 2007b; Kennedy et al., 2011a, 2011b; Northern Climate ExChange, 2013, 2015a, 2015b, 2015c). These surveys, developed in partnership with community members, are intended to inform climate change adaptation strategies for infrastructure and communities. To date, none of these studies have addressed impacts of permafrost thaw at the scale of the traditional lands of a First Nation.

Because of the remote location of Jean Marie River (JMR) (Figure 1), Jean Marie River First Nation (JMRFN) does not have easy access to food supplies from larger centres. The First Nation uses its traditional territory to provide food to its members by hunting, trapping, fishing, and harvesting berries and other food and traditional medicines from the land. These activities are essential to their survival and are deeply anchored in their culture.

JMRFN's traditional territory is located in the Great Slave Plains eco-region, a part of the Taiga Plains eco-zone. It consists of low rolling marsh lands and dense spruce, pine and poplar forests. The community is at the boundary between the extensive and sporadic discontinuous permafrost zones (Heginbottom et al., 1995). Smith and Burgess (2000, 2002) have reported that the permafrost that is present in the area has mean annual near-surface ground temperatures ranging from -2 to 0°C, and thickness of less than 10 metres. This makes the permafrost very sensitive to climate warming.

Culturally important areas of land surrounding JMR are in peatland, woodland and shrubby areas that are underlain by permafrost which is currently undergoing extensive degradation. Thermokarst processes are changing the landscape, the vegetation, and altering wildlife habitat and impacting food security/safety, access to, and supply of, cultural resources such as traditional medicines, travel safety, water quality and exposure to diseases, illnesses, and contaminants associated with permafrost degradation and the health of plants and animals (Callahan et al. 2005, Walsh et al. 2005).

To address these issues, the JMRFN initiated a project to assess the thaw vulnerability of the permafrost in its traditional territory and to analyze how this may affect the community particularly in terms of food security. The first task was to identify forested and shrubby areas that are likely to change into lacustrine or swampy areas following permafrost degradation. This task resulted in a map of permafrost thaw vulnerability for the JMRFN traditional territory. The second task was to relate the thaw vulnerability map to knowledge of how the land is traditionally used and where key species-of-interest are known to be. The outcome of the second task is an assessment of how activities such as hunting, trapping, gathering, and other cultural activities will be impacted by landscape change and permafrost thaw.

The final result is a series of climate change vulnerability maps of traditional use areas within 20 to 40 km from the community.

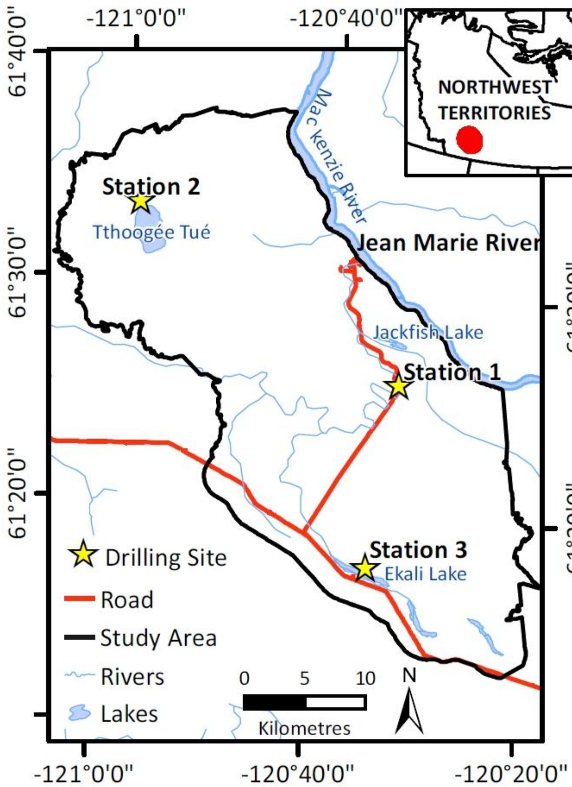

Figure 1. Studied area

Figure 2. Area with heavy permafrost degradation near Thoogée Tué

2 METHODS

As a community-directed project, the methods, selection of field sites, and findings were discussed thoroughly with key groups within the community. A focus group including JMRFN officials and elders took an active role in all project stages, while community meetings were used to gather or share information with a broader audience at key times (e.g., prior to fieldwork, prior to the assessment of impacts of permafrost thaw on traditional uses, and at the end of the project). Input from these activities was central to ensuring that the end products were addressing the questions and priorities of the community.

2.1 Mapping vulnerability to permafrost thaw

The presence and equilibrium of permafrost is influenced by factors including climate, the nature of the ground (i.e. the geology), surficial conditions such as snow cover, vegetation, and hydrology, and the exposure to the sun (slope, aspect). To determine permafrost distribution and its thaw sensitivity at the traditional territory scale in this survey, we used the nature of the soil, surficial geology, and the vegetation. These factors were chosen primarily because of the availability of data, the time available for conducting field work, as well as the general scheduling of the survey.

2.2 Air-photo interpretation

Aerial photographs were used to interpret landforms and surficial deposits. The cartography resulting from air-photo interpretation is based on the recognition of landforms and deposits that are attributable to the Quaternary history of the studied area (i.e. landforms inherited from the evolution of the landscape during the last 2 million years).

In the case of the JMRFN traditional territory, this may include glacial deposits, such as moraines and tills, fluvio-glacial deposits, usually gravel, and glacio-lacustrine deposits comprised of clay or shore sand. Some of the deposits and landforms may be more favorable to the presence of ice-rich permafrost than others. Also, some landforms are directly attributable to the presence of permafrost (French 1996). These landforms were mapped as an indicator of the permafrost occurrence in the area.

2.3 Field investigation

Field investigations were planned using preliminary air-photo interpretation and surficial geology maps by Duk-Rodkin (2005a, 2005b), as well as discussion with the focus group. Areas likely to being underlain by permafrost were identified. Information gathered from the community meeting was also used to orient the survey. Sites of interest that could be significantly impacted by potential future climate change in terms of permafrost degradation were identified. Three sites were selected:

Site 1, located 230 m East of the access road (61.43411°N, 120.5477°W), was selected because the site consisted of heave mounds that are sensitive to permafrost disturbance. This site was easy to access from the JMR access road.

Site 2, in an area known as Tthoogée Tué (61.56023°N; 120.9752°W), was selected for both cultural and environmental reasons. This is a hunting and trapping area where frozen mounds and permafrost plateaus are now collapsing. This site was accessed by helicopter.

Site 3 (61.295654°N; 120.580582°W) consists of a peatland with heave mounds and permafrost plateaus. It was selected because of its proximity to Ekali Lake, an area with a cultural and ecological importance. This area is often frequented by caribou. This site was accessed by boat and on foot.

At each site a borehole was collected to determine the active layer thickness, soil nature, and ground ice content. Complete, unaltered cores were collected using a light, portable earth drill (Calmels et al. 200X). The boreholes were then instrumented with a 4-Channel External Data Logger U12-008 that recorded temperature at four different depths with an accuracy of ±0.25°C. The temperature data were used to record ground thermal regime and to assess the permafrost susceptibility to degradation. The temperatures were collected a few days after installation of the loggers in September 2013, and again in March 2014.

Further field work including excavation, permafrost probing, and shallow digging were carried out by travelling by foot, ATV, boat, or helicopter was carried out in order to assess the occurrence of permafrost in other areas of interest identified by the focus group and during the aerial photo interpretation. A vegetation survey was also performed in September 2012 (See Section 2.5).

2.4 Surficial geology analysis

Based on the results from the field investigation, it is possible to infer the presence of permafrost from surficial geology and geomorphologic features. Geological deposits and geomorphologic features including periglacial landforms were mapped using aerial photographs ordered from the National Air Photo Library and surficial geology maps from the Geological Survey of Canada (GSC).

The geological deposit analysis was based on a geological map entitled Surficial Geology, Fort Simpson (95H) that was made available in digital files by the GSC (Duk-Rodkin 2011). This map was based on field survey. In it, the presence of permafrost in the area was linked to the presence of fenlands and peatlands.

In summer 2012, permafrost was also observed in lacustrine plains associated with aeolian complexes and also in glacio-fluvial plains. In 2013, permafrost was observed in two more geological deposits: an alluvial fan associated with an aeolian complex and a lacustrine complex associated with till plain. Colluvial complexes and the landslide deposits were also considered to be vulnerable deposits because of their sensitivity to landslide. Moreover, the landslide deposit also has a tendency towards slope instability (Duk-Rodkin 2011).

2.5 Vegetation analysis

In discontinuous and sporadic zones, permafrost is more likely to be associated with fine-grained sediments or peat deposits where there are typically thick organic mats (mosses and other similar ground covers), and coniferous vegetation (Brown 1973, French 2007). This means that mapping the types of vegetation covering a terrain can also be used as a means to map permafrost distribution.

In 2012, the most recent Landsat imagery available was used to produce a land cover map around JMR with a multispectral imagery gathered by the Thematic Mapper on Landsat 5, on August 27, 2011. It contains seven spectral bands (blue, green, and red visible bands, as well as near-infrared, two mid-infrared bands, and one thermal infrared band) that can be used to discriminate various types of vegetation. The spatial resolution of the original image is 30 m X 30 m per pixel.

A vegetation survey was performed to calibrate the vegetation analysis. Several areas representative of different vegetation types were visited. These “training sites” were used to characterize five classes of vegetation. A draft of the classification was created and then used to randomly select verification sites for each class. The verification sites were visited in the field to confirm or refute the information given by the preliminary draft classification. From there, it was possible to perform the final vegetation classification.

Four land-cover categories were created: mixed or deciduous forest; coniferous forest; peatlands with a thick cover of mosses, especially sphagnum mosses; and peatland with shrubs, graminoids, and/or sedges and other aquatic plants.

In the context of warming, discontinuous extensive to sporadic permafrost zones such as JMR, deciduous forests can be associated with the absence of permafrost. Deciduous trees are often indicators of well-drained terrain (i.e. soil with coarser deposits, where the active layer is relatively thick). Conversely, coniferous trees such as black spruce are more adapted to poorly drained and permafrost terrains. These types of trees may often be associated with thick organic cover and can be found on permafrost mounds and plateaus. Peatlands with thick cover of mosses and peat are more likely to harbor permafrost terrain because organic cover has thermal properties favoring permafrost aggradation. Meanwhile, the moisture found in grassy peatlands does not help permafrost growth.

With this information, we classified each vegetation class as an indicator for presence of permafrost:

- Peatland with shrubs, grasses and sedges = no probability of presence of permafrost
- Mixed and deciduous forest = low probability of presence of permafrost
- Coniferous forest = medium probability of presence or permafrost
- Peatland with mosses and sphagnum = high probability of presence or permafrost

A map of permafrost distribution was developed based on vegetation analysis using ArcGis.

2.6 Combined analysis and ranking

The map of vulnerability to permafrost degradation was developed using ArcGIS. The vulnerability map ranked the probability of extensive landscape change, namely, the conversion of woodland area into ponds and/or wetlands, occurring as a result of complete permafrost degradation. To create the vulnerability map for the whole area, the probability of permafrost thaw based on surficial geology (inferred from surficial geology maps, field sampling and air photos), was combined with the probability of permafrost presence based on vegetation (inferred from Landsat imagery). Vulnerability to permafrost thaw is described in three categories: high, moderate, and low vulnerability. Highly vulnerable areas are likely to have extensive permafrost degradation that will completely transform the landscape. Medium vulnerability areas are expected to undergo slower or less complete changes in landscape. Low vulnerability areas will have little change in landscape, either due to lack of permafrost, or due to resilience of existing landforms and vegetation. The complete ranking system is presented in table 1. The resulting map (Figure 2) gives a more detailed classification of vulnerability to permafrost degradation.

2.7 Impact Mapping

The final stage of the study was to determine the impact that permafrost degradation will have on food security, and other traditional activities. In this step, the vulnerability map was overlaid with spatial traditional land use (TLU) information collected from previous studies to bring a new perspective in terms of potential climate change impacts on the JMRFN.

Several maps were developed based on data from the JMRFN's TLU database. In this database, each point represents the location of the killing or sighting of an animal of a specific species. Therefore, each point is an indicator of presence of the species, and the location can be considered to be part of the animal's habitat. The data were sorted by category to produce thematic maps that were later overlapped with the vulnerability map. This allowed the calculation of the percentage of sites located in each level of vulnerability for each type of animal.

3 RESULTS

3.1 Permafrost field assessment

In the area of JMR and the access road (Sites 1 and 3), permafrost sites are mostly associated with wetlands and peatlands. At these sites, the presence of permafrost mounds (palsas) are indicators of potentially ice-rich permafrost. Drilling confirmed that the presence of permafrost was related to the occurrence of a thick organic cover. Located in a paleochannel eroded by the flood of the glacial Lake Agassiz (Couch and Eyles 2008, Smith 1994), this organic cover developed over poorly drained areas where lacustrine clay deposits were exposed at the ground surface.

Terrain located in Tthoogée Tué area (site 2) has a different geological history than the sites located in the paleochannel. The region is lacustrine and is surrounded by unfrozen wetlands. Permafrost is found in conjunction with peatland, woodland and shrubby areas. The permafrost of the area appears to be undergoing extensive degradation; forested areas are being replaced by wet grassland and lakes. In this area, permafrost is often present in mounds and permafrost plateaus with an elevation exceeding 5 m. These landforms are currently undergoing heavy degradation processes, being replaced by thermokarst ponds.

Table 1: Combined ranking system for probability of landscape change due to permafrost degradation.

Probability of Thaw-sensitive permafrost based on geology					
	High	Low	Medium	High	High
	Medium	Low	Low	Medium	High
	Low	Null	Low	Medium	Medium
	Null	Null	Null	Null	Low
		Null	**Low**	**Medium**	**High**
		Probability of permafrost presence based on vegetation			

The ground temperature survey indicates that the permafrost is very warm at the three stations: -0.1°C at station 1, -0.25°C at station 2, and 0°C at station 3. The temperature profiles remained very close to the 0°C threshold and did not display significant temperature variation during the fall and winter freeze back of the ground. This indicates that the content of liquid water must be important, preventing the ground from cooling off during the freezing season.

Due to the warm ground temperatures, the permafrost at these stations is on the brink of degradation. It is likely that the only factor delaying permafrost at these sites is the large amount of excess ground ice. This ground ice, ranging from 40 to 80%, requires the input of a significant amount of heat energy to change into liquid water. Yet, when melting, the ground ice will leave voids in the ground that will translate into ground surface subsidence. With the thaw of permafrost and its ground ice, the permafrost mounds and plateaus will withdraw, making room for ponds and lakes; the vegetation will be submerged. Significant changes are likely at the three stations when permafrost thaws.

3.2 Permafrost thaw vulnerability

Figure 2 shows the vulnerability to thaw for the JMRFN traditional territory. Permafrost is present in 51.5% (483.6 km²) of the study area. Of the total area, 35.2% (170.22 km²) has a high level of vulnerability and 15.9% (76.89 km²) has a medium level of vulnerability. Figure 2 also shows a large area in the western portion of the study area around Tthoogée Tué that is already undergoing severe permafrost degradation. The degradation process was observed in the field and was also clearly identified from the air photo interpretation. This represents 16.2% (78.34 km²) of the study area.

3.3 Impacts

JMRFN relies on wildlife and plants for food security. They identified six categories of interest for further scrutiny (Table 2, Column 1). This table shows the percentage of sites indicating the presence of wildlife and activities that will possibly be impacted by permafrost thaw. The remainder of this paper focusses on big game and other traditional activities that relate strongly to food security.

Table 2. Percentage of sites indicating the presence of wildlife and activities possibly impacted by permafrost thaw.

	Presence of activity per vulnerability areas (%)		
	High	Medium	Total
Big Game	24.4	12.8	37.2
Small Game	23.4	16.3	39.7
Furbearer	17.7	16.1	33.9
Bird	12.2	10.9	23.1
Gathering	17.6	15.7	33.3
Occupancy	15.8	41.5	57.4

Figure 3a shows the big game data overlapped with the final vulnerability map. Big game animals such as moose and caribou are an important portion of country food diet in JMR. The amount of meat from these animals allows sharing among families and provides food for community meetings and events. The survey shows that about 37% of sites frequented by big game overlap areas that are highly vulnerable to permafrost thaw. Caribou are more frequently sighted or harvested in the southern part of the study area and a large portion of their habitat overlaps with highly vulnerable areas to permafrost thawing. Moose are more frequently sighted or harvested in the northern part of the study area where they can find more muskeg. A majority of moose sites overlap with medium or high vulnerability areas. Community members have reported that moose have more difficulties travelling in muskeg because the ground underneath is soft and not frozen anymore and therefore less stable. Meanwhile, bear appear to be the least impacted of the big game species.

The landscape changes induced by permafrost thawing and described in this report not only affect food security, but also traditional activities in general. Travel and building of cabins, tent frames, camp fires, are all adversely impacted by permafrost degradation. In addition, burial sites, birth sites, places where people gather, food caches and many other sites that are very important in JMRFN culture are being impacted. A very large part of the land is used for all of these activities and any changes affecting the land are likely to affect these activities as well. Table 2 shows that 57.4% of the occupancy sites overlap with areas vulnerable to permafrost thawing. The location of these sites as well as the travel routes is shown in Figure 3b. All documented travel routes cross highly vulnerable areas. Figure 3b also shows a high concentration of occupancy sites around Ekali and Sanguez Lake. Both of these lakes are surrounded by high and medium vulnerability areas. The landscape changes in this area are likely to be significant in the future and consequently JMRFN expects to have more difficulties in practicing traditional activities in this particular area.

4 DISCUSSION

The final results reflect the fact that the JMRFN traditional territory is located at the boundary between the sporadic discontinuous permafrost zone where 10% to 50% of the land surface is underlain by permafrost and the widespread discontinuous permafrost zone where 50% to 90% of the land surface is underlain by permafrost. Patches of permafrost can be very large; approximately 16 by 20 km around Tthoogée Tué, approximately 6 by 16 km around Ekali Lake, and 2 by 10 km in the Eastern area closer to the MacKenzie River. Between these last two patches is the only area that doesn’t have any patches of permafrost. The rest of the study area is dotted with small permafrost-free patches.

The large patches of permafrost represent areas that will become increasingly hazardous for travel; this is where most of the landscape changes are expected to occur. In these areas, community members of JMR should expect to find more fallen trees and an increasing number of wet areas at these locations. The final vulnerability map has been presented to the community in the hopes that they can use it as a guide when traveling on the land. For example, when planning to cross highly vulnerable areas, there may be increased need to travel in groups and with a chain saw or equipment in order to clear trees that have fallen due to permafrost thaw. For harvest of animals that are present year-round, the timing of trips may also need to change to colder periods of the year.

The changes in these large, vulnerable areas are likely to affect the wildlife. Large portions of their habitat are bound to be impacted in such a way that their diet and migration patterns will be affected. As previously mentioned, the western area around Tthoogée Tué is already being affected by permafrost degradation and, therefore, exhibits greater landscape changes. As the permafrost mounds of this area continue to thaw, more and more water will be released on the surface and it is doubtful that terrestrial animals like rabbits will be able to stay in this area.

5 Conclusion

This study represents the first attempt to identify and quantify the potential impacts of permafrost thaw on the food security of a northern community. It provides a template for similar surveys in other communities.

Permafrost thaw will affect food security in terms of availability and accessibility, by reducing access to important areas for harvesting country food, and changes to the terrain and the ecosystems that make up these landscapes. Water quality may also be affected, impacting fishing, drinking water quality, and potentially triggering changes to the stability of the community's water supply.

More broadly, permafrost thaw may impact other culturally significant practices such as traditional land use and occupancy practices, Traditional Knowledge exchange, and JMRFN individual and cultural relationships with the land.

This survey only unveils one corner of an issue having intricate ramifications. The authors and JMRFN is eager to continue work to address sub-issues separately in the upcoming years.

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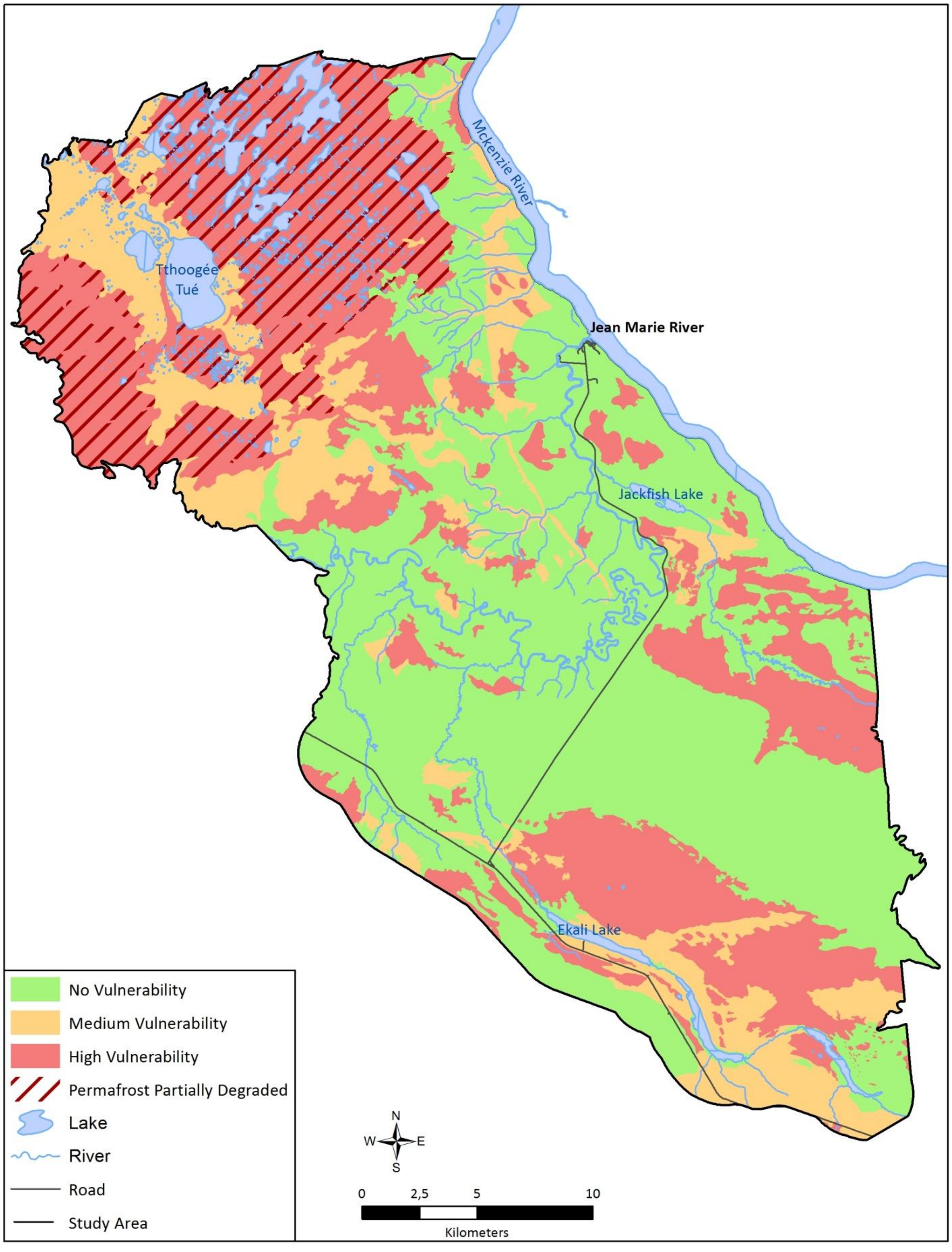

Figure 3. Final map of vulnerability to permafrost thaw for JMRFN traditional territory.

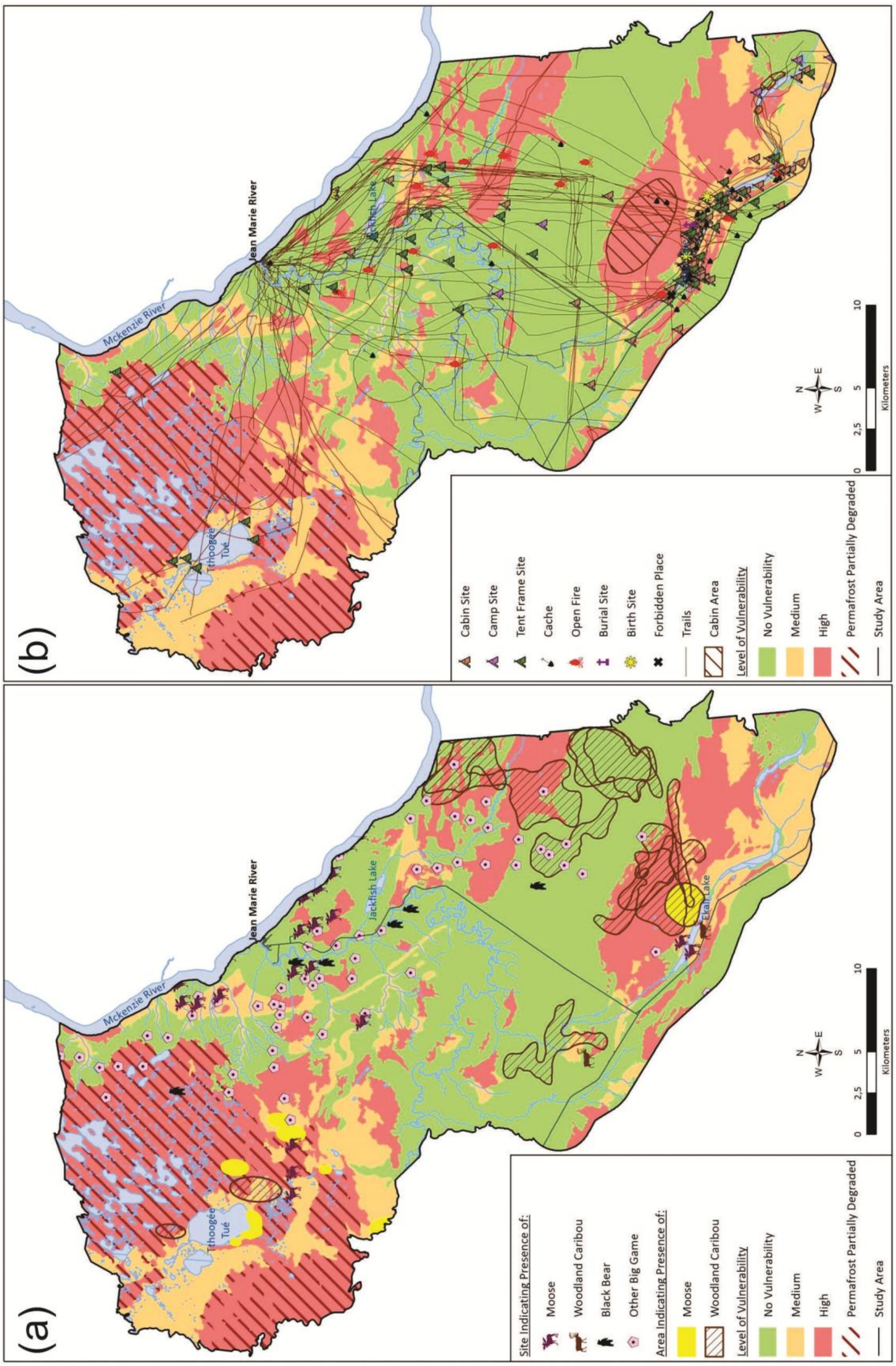

Figure 4. Big game (a) and occupancy (b) data overlapping with the map of vulnerability to permafrost thawing