Chapter 4

Increasing the Adaptive Capacity of Indigenous People to Environmental Change: The Potential Use of an Innovative, Web-Based, Collaborative-Geomatics Informatics Tool to Reduce the Degree of Exposure of First Nations Cree to Hazardous Travel Routes

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Additional information is available at the end of the chapter

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Abstract

The arctic and subarctic regions of Canada are experiencing amplified climate change impacts, which are disproportionately impacting Canadian indigenous populations' ability to safely travel on land to acquire resources. Less predictable and more dangerous travel conditions are impacting not only the health and safety of individuals but also the traditional lifestyles that are vital to the cultural well-being of these indigenous communities. The University of Waterloo's Computer Systems Group has developed a novel decision-support tool termed "Collaborative-Geomatics." This web-based informatics tool can allow for the community to monitor, in real-time, the safety of travel routes. Using handheld GPS tracking systems, the utility of the geomatics system to present real-time travel conditions was carried out in a Canadian First Nations community, located along the Western James Bay coast. The results of this study showed that the collaborative-geomatics tool offers the potential to monitor and store information on the safety of travel routes, helping to promote adaptive capacity and aid in knowledge transfer within arctic and subarctic indigenous communities.

Keywords: arctic, indigenous, climate change, collaborative-geomatics, safe-travel

1. Introduction

1.1. Global and arctic climate change

With the release of the Fifth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), it is now unequivocally certain that global warming is due to anthropogenic emissions, resulting in widespread social and ecological impacts [1, 2]. Globally, the atmosphere and oceans have warmed, and there have been more frequent heavy precipitation events and Heat waves [3]. It is becoming apparent that social systems, like ecological ones, are vulnerable to climate change, especially to extreme environmental events [3]. The spatial convergence of climate change impacts will likely compound risks to already vulnerable populations, globally [4]. Regions such as the Arctic are predicted to experience disproportionally greater ecological and social impacts from global warming [5]. Indeed, the duration of the sea-ice-free season has decreased in the arctic–subarctic region of Canada [6], and sea levels have changed and will continue to change [7, 8].

The Canadian arctic and subarctic regions have already experienced a general warming of up to 5°C, the most rapid rates of increasing average surface temperatures in the world [9–11]. Thinning Arctic Sea ice has been documented since 1979 [12]. Satellite imagery of Arctic Sea ice has shown a disturbing pattern in the rate of decline in ice extent. Winter months show a rate of decline in ice occurring at 3.5–4.1% per decade, while summer shows a rate of decline of 9.4–13.6% per decade [12]. Current models are predicting a continued and unprecedented decline in sea ice in the Arctic. Sea ice retreat in the Arctic will significantly impact arctic precipitation; the resulting increase in surface evaporation will lead to an amplified arctic hydrological cycle [13].

Climate models and precipitation trends indicate that there will be a significant increase in rainfall in arctic regions [6, 14–17]. By the end of the twenty-first century, it is predicted that precipitation rates in arctic regions will increase by 50% and will peak during the autumn and winter months, resulting in a likely increase in river discharge [13]. It is very likely that continued warming will result in changes to spring snow and river melt timing, pushing the spring peak flows earlier [18].

Increased atmospheric warming has also impacted permafrost in the Arctic. Since the early 1980s, permafrost temperatures have warmed by approximately 3°C, resulting in an overall thinning and loss in the extent of permafrost. The southern boundary of continuous permafrost in the arctic–subarctic region has already advanced northward by approximately 50 km [12]. Warming global temperatures are producing climate extremes. Arctic regions have already recorded increased wind speeds in all seasons [18]. Changes to sea-level pressure around mid-latitudes have resulted in longer and more frequent winter storms over the lower Canadian arctic [18]. Continued global warming is predicted to not only have devastating and irreversible ecological impacts on the arctic–subarctic environment, but it is now becoming apparent that there will also be equally significant social impacts on the individuals and communities who call this region home.

1.2. Risk and challenges associated with climate-related impacts

Globally, indigenous groups represent some of the most vulnerable populations, but are rarely considered in climate change discourse [19]. It is expected that the world's indigenous populations, living in arctic and subarctic regions, are some of the most vulnerable and will experience the greatest impacts of climate change [20, 21]. Within Canada, indigenous communities are defined as including First Nations, Inuit, and Métis people. The 2011 Canadian National Household Survey determined that just over 4% of Canada's population, approximately 1.4 million people, is indigenous [22]. Canadian indigenous people experience many inequalities compared to Canadian nonindigenous people, such as shorter life expectancy, higher rates of diabetes and infectious disease (e.g., tuberculosis), and higher rates of suicide and substance abuse [23, 24]. Approximately half of Canada's indigenous population—referred to as Aboriginal Peoples in the Canadian Constitution—live in northern Canada, on reserves, or in rural and remote communities [25]. Remote indigenous populations usually share close relationships with the land and practice traditional land-based lifestyles [26, 27]. Thus, indigenous groups living in Canada's arctic and subarctic regions are particularly vulnerable to climate change due to their interconnectedness with the land [25, 28].

Traditional ways of living include hunting and harvesting practices that are guided by seasonal cycles. Using environmental indicators such as seasonal cycles, indigenous groups have been able to predict seasonable changes and weather patterns [29]. This indigenous knowledge about the land, termed "traditional ecological knowledge (TEK)" can be defined as being "a body of knowledge and beliefs transmitted through oral tradition and first-hand observation. It includes … a set of empirical observations about the local environment … With its roots firmly in the past, TEK is both cumulative and dynamic, building upon the experience of earlier generations and adapting to the new technological and socioeconomic changes of the present" [30]. Therefore, this knowledge played an important role in the adaptation to environmental conditions on a seasonal and yearly basis [31]. However, social inequalities such as the introduction of residential schools in Canada in the 1930s have resulted in a loss of language, culture and knowledge, and the disruption of transmission of TEK between generations [24, 32]. This loss of TEK, coupled with preexisting marginalization, and the increase in unpredictable environmental changes (e.g., increase in the number and severity of storms, increased flooding, sea ice, and river changes) as a result of climate change reveal the vulnerability of northern Canadian indigenous communities. Climate-induced changes are expected to create challenges for indigenous people living in Canada's north, some of which are already being seen. These challenges, both observed and predicted, can be related to access to resources, and health and safety [33].

The ability to travel on land, ice, snow, and by water to acquire resources is an integral part of many indigenous peoples' lifestyles. Traditional ways of life for many indigenous communities involve the consumption of seasonal foods, such as waterfowl, game mammals, and fish [29]. Changes to the timing of ice breakup and river depths can affect access to family hunting camps. Often traveling by boat or snowmobile, changes to ice depths, snow type, river depths, and ice-free areas can significantly hinder the ability to get to these camps along with the length of time that can be spent there [33]. A recent study showed that one of the most significant impacts of changing winter conditions is the inability to travel onto the land and participate in traditional harvesting activities, resulting in emotional feelings of being trapped and imprisoned [34]. Furthermore, participants reported changes to their eating habits, consuming more costly and less nutritious store-bought foods.

Related to this ability to access traditional resources and the importance behind such resources, the safety of indigenous people while out on the land is an important challenge when facing the impacts of climate change. Younger generations, especially, are viewing the land with more fear and uncertainty and believe that it is less accessible [35, 36]. Many safety issues are arising in relation to sea ice and early spring thaws. In many indigenous communities, sea ice is important for winter hunting activities such as hunting sea mammals [33]. However, ice conditions are less reliable, and sudden changes in ice conditions are becoming more common, resulting in safety issues for those who are out on the land and water. Changes in ice thickness, ice condition, ice movement, and the extent of open water can become a safety issue While out on the ice hunting. Also, early thawing of ice and ground along bush trails is resulting in stranded snowmobiles and increased risk of drowning and hypothermia [37]. Sudden changes to wind conditions often occur rapidly, resulting in dangerous and potentially life-threatening conditions for those already out on the land and water, making navigation difficult. Research has shown that the incident rate of accidents in northern coastal indigenous communities has increased as a result of changes in weather [37]. Furthermore, an increase in extreme weather events, such as an increase in unpredictable and intense summer storms, presents a risk to boaters out on the water [37, 38].

Cultural impacts as a result of these climate-induced changes are affecting the psychological status of many indigenous people [39]. Since traditional harvesting activities allow for the development of social relationships and the processing and consumption of traditional foods [39], any disruption to these activities negatively impacts indigenous culture.

Safety while out on the land relates to the predictability of environmental conditions (e.g., weather) [33]. Historically, indigenous people have been able to predict environmental conditions through their intimate knowledge of the land; however, it has become more difficult to use traditional knowledge to predict environmental events (e.g., ice breakup and weather patterns), as these things are occurring "at the wrong time" [33]. There is concern that as adaptive and flexible as TEK is, the rate and magnitude of climate-induced change might be too unpredictable for TEK to adapt [33, 40]. Therefore, there is a need for decision-support tools that are culturally appropriate and community-informed that can display real-time information on the safety of travel routes in arctic and subarctic indigenous communities [41–43].

1.3. Using geomatics to make travel safer

Since the 1990s, indigenous communities throughout Canada have been using Geographic Information Systems (GIS) for mapping [44], defined as "an organized collection of specific computer hardware, software, geographic data and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information (e.g., raster/vector) that can be drawn from different sources" [45, 46]. Within indige-

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nous communities, GIS have been used to map information, such as traditional land use (e.g. hunting, fishing, and harvesting) [44, 47]. The ability to map traditional land-use activities and assets has played an important role in the collection and storage of TEK. Unlike traditional paper maps, GIS maps have the ability to be easily developed and modified to represent and archive current environmental conditions and/or traditions [44]. However, there has been concern, within the academic arena, that GIS can be a marginalizing technology [48]. Concern over how people, space, and the environment were represented by GIS systems has resulted in the shift from GIS technology to public participation GIS (PPGIS).

PPGIS draws upon conventional GIS techniques and builds upon them, allowing for what has been described as "a wider, more distributed use and development of geographic data, information, and knowledge" [49]. Although hard to define, PPGIS has been described as "the use of geographic information systems (GIS) to broaden public involvement in policy making as well as to the value of GIS to promote the goals of nongovernmental organizations, grassroots groups and community-based organizations" [49, 50]. PPGIS supports a range of interactive approaches and web-based applications that focus on ease of use and accessibility to support youth, elders, women, First Nations, and other vulnerable segments of society that have often been marginalized and excluded from decision-making processes [48]. Within arctic and subarctic indigenous communities, PPGIS offers the opportunity for communities to work together and build a database of value-based information [50]. This collection of information can lead to increased adaptation with respect to the impacts of climate change, through empowerment and knowledge sharing, between community and family members. Travel route (e.g., bush trails, ice roads) mapping on a real-time basis can help community members to be proactive and make informed decisions, on the safety of trail and ice-road conditions prior to heading out onto the land. It is with this knowledge, and First Nations community involvement, that the Computer Systems Group at the University of Waterloo developed a PPGIS termed "Collaborative-Geomatics."

Geomatics is a method used to link geospatial data (e.g., cities, regions, and countries) and attribute data (e.g., social, economic, ecological, and cultural data) [51]. Collaborative-geomatics is a PPGIS mapping tool based on geo-web technology where participants can collaborate, discuss, and communicate about community-based cultural asset maps and databases [49, 52]. The use of the collaborative-geomatics informatics tool by First Nation groups has been shown to build capacity in the communities through the complementary archiving of Western science and TEK [53], while having the potential to use the collaborative real-time function to plan and deal with the complex and dynamic nature of environmental change within subarctic environments. In this context, we worked with a subarctic First Nation community to develop and implement a collaborative-geomatics informatics tool that can use real-time geospatially referenced environmental change information to reduce the degree of exposure to unsafe travel routes and support the growth of community-wide adaptive capacity. In this chapter, we will present results from the initial step in our iterative process, related to the development of a decision-support tool (i.e., the collaborative-geomatics informatics tool) to reduce the degree of exposure of First Nations Cree people to hazardous bush travel routes.

2. Methods

2.1. Study location

The western James Bay region of Ontario, Canada, is populated by ~10,000 First Nation Cree who inhabit four coastal First Nations communities and one town (i.e., Moosonee; **Figure 1**) [54]. Within Canada, First Nation Cree make up the largest and most widely distributed populations of Aboriginal groups. Our focal community, Fort Albany, is located on the Albany River (52°15′N, 81°35′W), being a remote fly-in community with a population of approximately 900 people. Year-round access to the village is by aircraft only, with ice-road access in the winter. The James Bay winter road is 312 km long and connects the First Nations community of Attawapiskat in the north to Moose Cree First Nation (i.e., the community of Moose Factory) in the south, running by the First Nations communities of Kashechewan and Fort Albany (**Figure 1**). The winter road is a vital connection for First Nations communities along the western James Bay coast. These roads provide access to hunting camps, fishing sites, firewood collection areas, and other important subsistence activity sites. The winter road is also a lifeline that connects families that are spread out between the communities along the coast. With access to Moose Factory and Moosonee in the winter (Moosonee is the northern terminus of the rail line),more northern communities have the ability to purchase less-expensive food and household supplies. Fiber-optics and/or satellite Internet connections are

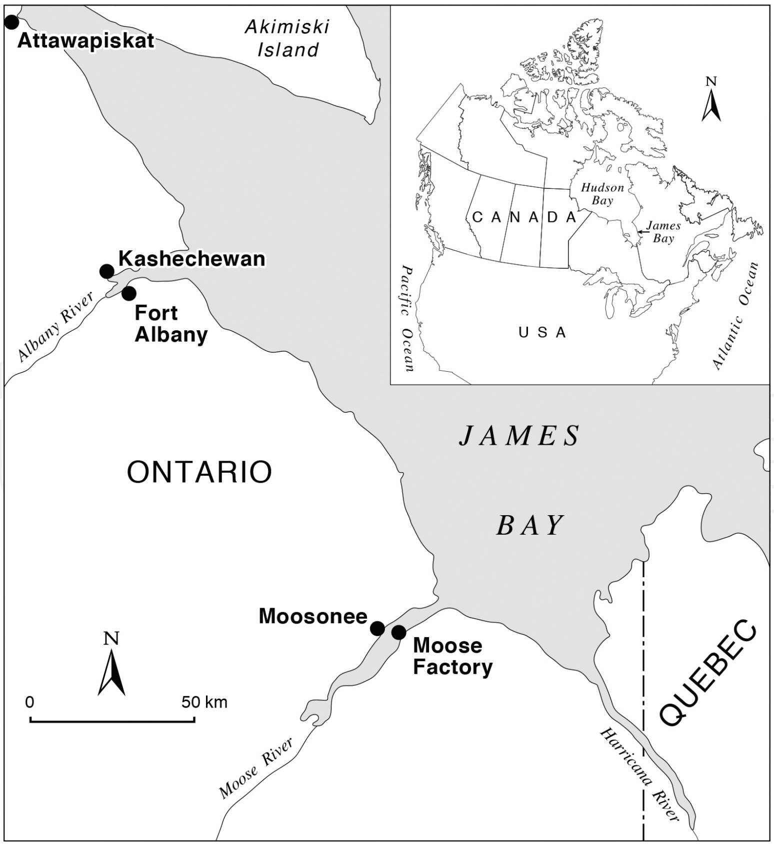

Figure 1. Map of the Mushkegowuk Cree First Nations territory, Western James Bay, Ontario, Canada.

available in all the western James Bay communities, with cell phone service only available in Moose Factory and Moosonee.

Fort Albany lies within the Mushkegowuk Territory (i.e., the western James Bay region), which is composed of ecologically important muskeg and wetlands. This region provides resources that many First Nations rely upon for subsistence, such as traditional game species (e.g., large ungulates, small mammals, game birds, fish), which are also socially and culturally important [55, 56]. Seasonal harvest of traditional foods is still an important part of life for First Nation Cree along the James Bay coast [29, 54]. The spring harvest, which begins in the middle of March, with the setting up of spring camps, is an important time of the year for the harvesting of traditional food that will be stored for consumption throughout the year. This time spent out on the land is also an important time where families come together to reaffirm their culture [57]. The spring hunt continues until river breakup, late April or early May [29, 58].

With respect to climate change, this region has already experienced significantly earlier sea-ice breakup events (0.8 days/year) and significantly longer sea-ice-free seasons (0.32–0.55 days/year) [6, 56, 59]. The Albany River and Attawapiskat River have also seen earlier breakup dates impacting the communities along their banks [56, 58]. Sudden warming events in the late spring combined with increased rainfall events have been attributed to extreme flooding events in the First Nations communities along the Albany River [60]. It is predicted that by the year 2100, in the western James Bay region, summer temperatures will increase by 4.1°C and winter temperatures by 7.5°C, along with an increase in extreme weather events [11].

2.2. The collaborative-geomatics informatics tool

The term collaborative geomatics is defined as "a participatory approach to both the development and use of online, distributed-authority, geomatics applications" [46]. Similar to neogeography, collaborative-geomatics builds upon the concept of PPGIS and collaborative GIS, where public participation is paramount [46]. Collaborative-geomatics is a system that is "centered on the designs, processes, and methods that integrate people, spatial data, exploratory tools, and structured discussions for planning, problem solving, and decision-making" [61].

What makes our geomatics decision-support tool unique is that it is based on the declarative application engine termed Web Informatics Development Environment (WIDE). The WIDE software toolkit [52] was developed over the last 17 years by the University of Waterloo Computer Systems Group (http://csg.uwaterloo.ca/) to construct, design, deploy, and maintain relatively inexpensive, secure, complex, web-based, and mobile systems [62]. The WIDE toolkit allows for a forms/wizards-based approach to system construction that supports the rapid development and modification of the tool. The WIDE toolkit is based on HTML, JavaScript, and PHP, and is provided as a software service over the Internet while supporting standard web browsers [46]. The security model is role-based.

The collaborative-geomatics informatics tool first deployed in 1992 supports a common high-resolution imagery reference map, similar to how Google Earth® presents data [49] (**Figure 2**). Some of the basic features of the tool include the entry of real-time geospatial information (oral, written, and visual [photographic, video]) that is securely housed within the system through accessibility safeguards (user names and passwords). The ability to develop groups within the system and send both public and private messages, similar to Facebook® Messenger®, supports the development of social networks (**Figure 3**). Furthermore, a forums section within the system allows for members to discuss a variety of topics with other users in their community network (**Figure 4**).

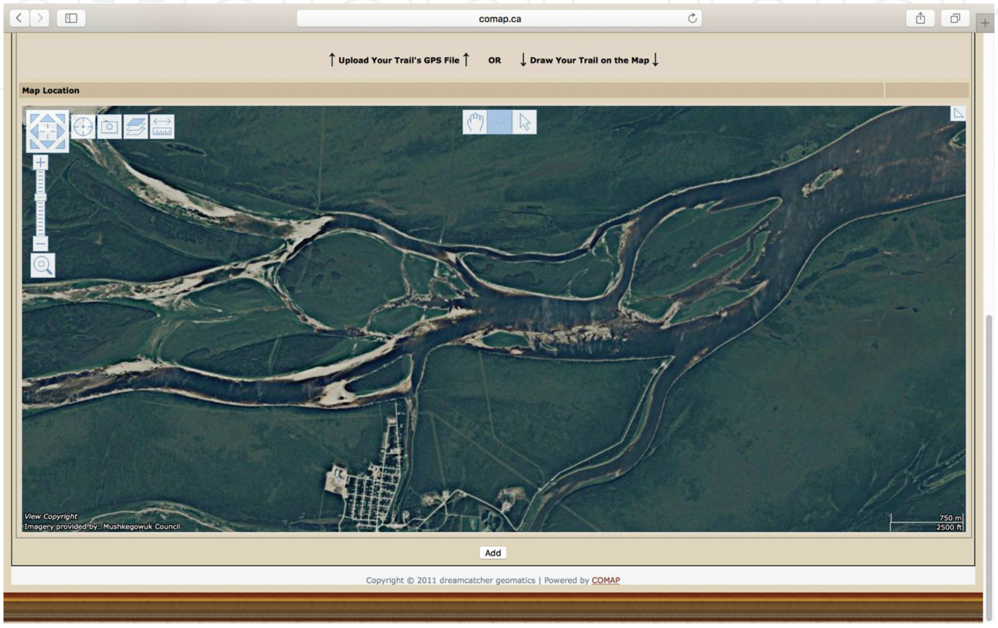

Figure 2. Satellite imagery on the collaborative-geomatics informatics tool of Fort Albany First Nations.

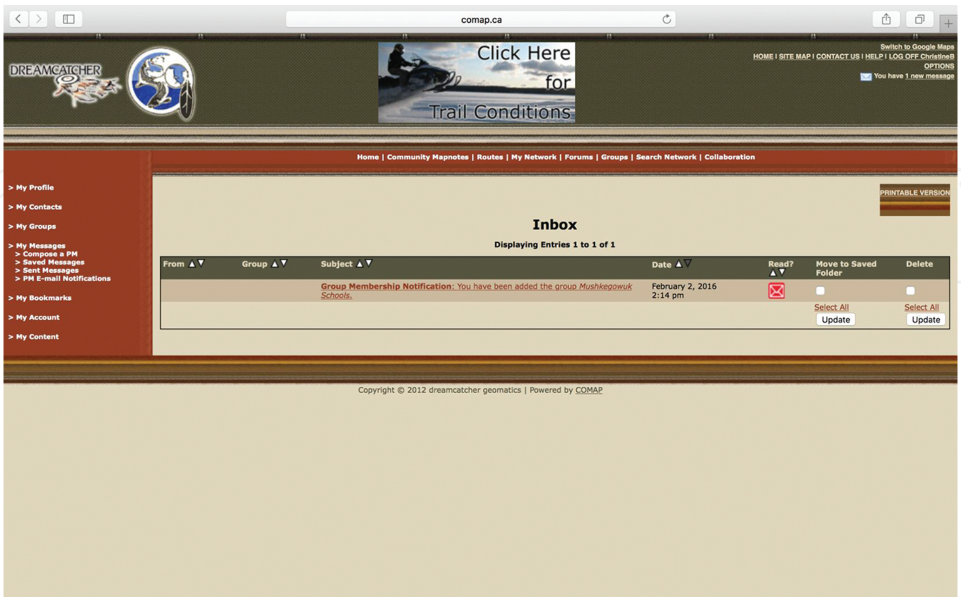

Figure 3. Group development application on the collaborative-geomatics informatics tool.

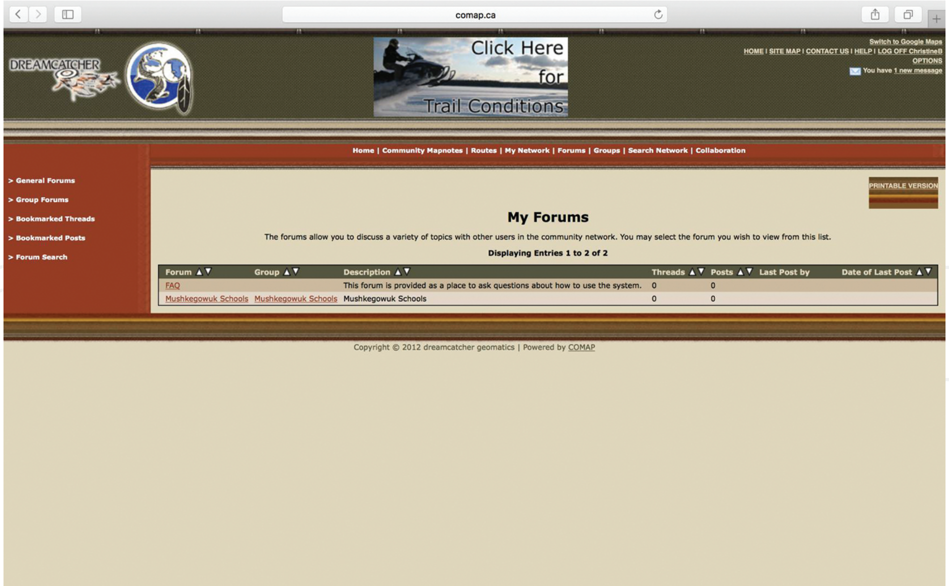

Figure 4. Forum development application on the collaborative-geomatics informatics tool.

The WIDE toolkit and collaborative-geomatics system is a proven technology that has been successfully used in over 80 governmental, community, resource management, and cultural heritage applications [46, 49]. One question that had been raised in the initial development of the geomatics tool with chiefs and councils of Fort Albany First Nations, and community members, was that of the security/confidentiality of TEK such as locations of hunting camps and community bush trails that will be collected and stored in the informatics tool. As TEK is an intellectual property, the security of TEK is of utmost importance. It was explained that all data (including TEK) would be stored only on secure servers within the communities (and/or secured data vaults off-site). Added to the physical security aspect of the tool, TEK would also be operationally secure with access to TEK on the tool being password-protected through profiles vetted by the chosen representatives of the individual communities. In some cases, differential access would be controlled by the chiefs and councils, while in other cases by family gatekeepers [49]. Granting of differential access was dependent on the type of TEK and the proposed use of TEK [46, 49]. It should be emphasized that other iterations of the informatics tool have provided storage for sensitive data for government ministries using exactly the same safeguards as described above [46]. Even the researchers do not have access to TEK on the tool unless granted by a gatekeeper. Our approach is guided by the indigenous principles of OCAP [63]: community Ownership, Control, Access, and Possession of their data. With the data housed within the communities and with the applications accessible through any Internet connection, the short-term accessibility is not in question. Over the medium- to long-term, there were concerns about the sustainability of a system that requires upgrades and development from a third-party organization. Given this issue, a stand-alone version of WIDE toolkit is currently being developed to allow communities to create their own unique applications for their informatics tool [49]. With some basic training, community members could develop and evolve their system to meet the future geospatial knowledge needs; this is one of the unique features of the WIDE toolkit's wizards-based approach.

2.3. Field testing of the informatics tool

In 2016, using handheld Global Positioning Systems (GPS) (Garmin® Oregon® 550) alongside a mobile Apple iPhone® GPS tracking app (Track Kit®), the western James Bay winter road was tracked by vehicle and the associated .GPX files were uploaded onto the collaborative-geomatics informatics tool. The Garmin GPS units have been shown by previous research in the same subarctic community to be easy to transport and were easy to use when tracking and georeferencing important locations [64]. The Apple iPhone® GPS tracking app (Track Kit®) was chosen to act as a backup, and to support the tracking of travel routes, due to the low cost associated with this program and the fact that many community members in Fort Albany own and use Apple products, such as the iPhone®, iPad®, and iPod®, all of which are supported by the Track Kit® app. Prior to using the app, the associated background map of the western James Bay coast was loaded from an Internet connection.

While mapping the winter road, important river crossings and areas known to flood were marked as waypoints and photographed. These waypoints and photographs were then uploaded onto the informatics tool. Community bush trails as identified by community members were also tracked using the same GPS devices. With the help of a community elder, these trails were driven by snow machine, and the use and cultural importance of these travel routes were discussed. These tracks were saved as .GPX files and uploaded onto the informatics tool as a bush-trail layer. Important landmarks were also marked using waypoints and photographed using both the GPS cameras and Apple iPhone® camera. The collaborative-geomatics informatics tool supports photographs uploaded in either .JPG, .PNG, or .GIF file format. The initial evaluation of the potential use of the collaborative-geomatics informatics tool was qualitative, using a combination of field notes and participant observations [64–66].

3. Results and discussion

3.1. Ease of use (hands-on testing)

With the use of handheld GPS tracking systems, the community bush trails and the winter ice road were successfully tracked and uploaded as .GPX files onto the collaborative-geomatics informatics tool. Pictures and important locations were also noted and marked as waypoints and uploaded (as .JPG files) onto the informatics tool (**Figure 5**). The ability to add geospatial information in the form of photographs/videos in real-time has the ability to provide even more detailed information on travel conditions.

Travel conditions were color-coded according to road and trail conditions (white = clear conditions; yellow = use caution, some areas may become dangerous; red = avoid use, dangerous conditions). Five of the most frequently used community bush trails were mapped along with the 312 km James Bay winter road, both north (**Figure 6**) and south of Fort Albany. Overall, the ability to track and map community travel routes and upload them as a layer onto the informatics tool was simple and accurate; we could visualize the winter road on our base layer, satellite imagery, to check the accuracy of the waypoints uploaded. While the Garmin®

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GPS units were easy to use, the ease of use and ability to take detailed pictures and notes on the mobile App made the Track Kit® app the most useful GPS unit in mapping travel routes. Furthermore, the preloaded high-resolution imagery on the App allowed for navigation while traveling along the bush trails and winter road.

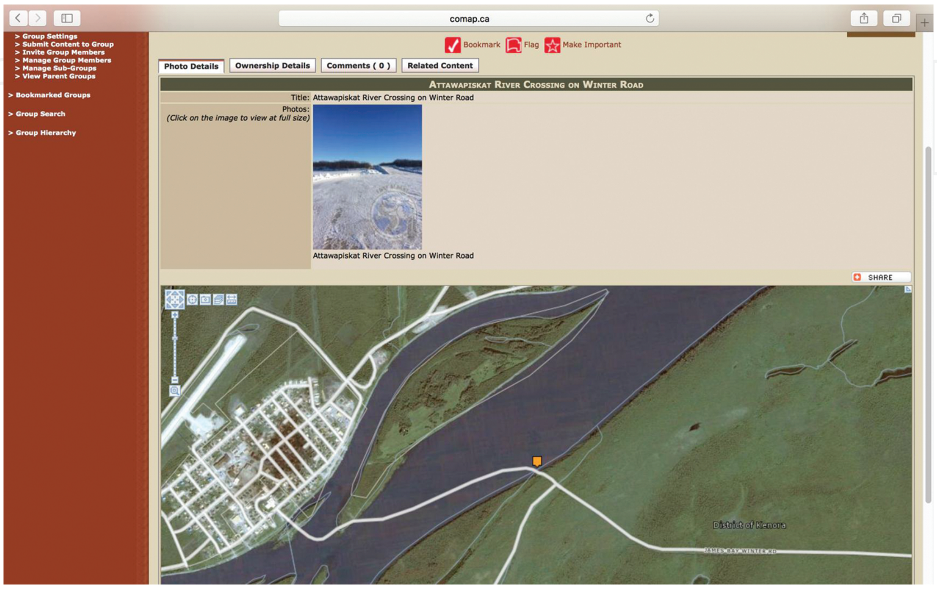

Figure 5. Geospatially referenced photograph of a river-crossing located on the James Bay winter road.

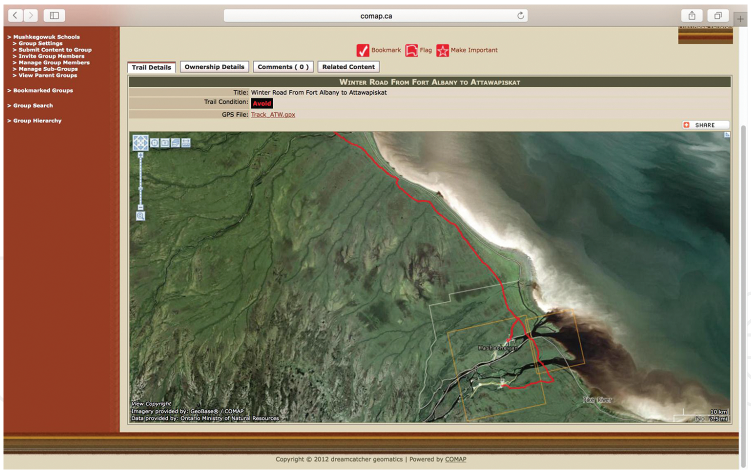

Figure 6. James Bay winter road, north of Fort Albany First Nations to Attawapiskat First Nation, tracked via handheld GPS units and uploaded as a layer onto the collaborative-geomatics informatics tool.

3.2. Potential use of the collaborative-geomatics informatics tool to build adaptive capacity

The meanings of names and relationships with the land are often propagated in narratives from elders to children. This oral history helps First Nation children to develop a sense of place within their environment from a very young age. This sense of place with the land and the memories and connections to a place are responsible for guiding future societal activities, land uses, oral history, and cultural transmissions of traditional knowledge. It is widely recognized that First Nations have developed an extensive understanding of the environment [67]. In the past, this knowledge of the environment was transmitted within and between generations, solely through oral traditions. This knowledge allowed First Nations to sustain their subsistence lifestyles and adapt to environmental change. Historically, northern indigenous communities addressed changes in the environment through TEK and skillsets acquired over generations on the land [33, 38]. Due to rapid changes in the environment as a result of a warming climate, knowledge once used to respond and adapt is becoming increasingly difficult to apply, thus decreasing First Nations' adaptive capacity [33, 38]. As environmental change continues in the arctic and subarctic regions, the resulting direct and indirect impacts have affected and will affect traditional lifestyles [11, 56]. At present, there is a great disconnect between what is currently being done on a global climate scale in terms of adaptation measures to climate change and what is needed locally [33, 68]. Increasing a community's adaptive capacity is one way in which vulnerability can be reduced [69, 70]. The collaborative-geomatics informatics tool is a decision-support tool that has the potential to increase the adaptive capacity of northern Canadian indigenous people to climate change impacts.

The following factors have resulted in less predictable and more dangerous travel routes: changes in the extent and extant of ice on lakes and rivers; later ice formation; earlier and more rapid spring melting; changes in the quality and amount of snow; increased precipitation, especially in the form of freezing rain; increased wind events; unpredictable wind directions; and an increased number of storms [42, 71–73]. The biophysical impacts of climate change on the safety of travel routes in the Canadian arctic and subarctic are having negative physical, social, cultural, and economic impacts on the indigenous communities in the region [27, 36, 41, 72, 74]. The collaborative-geomatics informatics tool has the potential to act as a decision-support tool to make bush travel safer, by promoting informed decisions prior to bush travel. The real-time capabilities of the tool can help determine the safest and most appropriate travel time and route prior to heading onto the land. This knowledge can not only directly protect the health and safety of individuals but also help relieve the anxiety associated with the unpredictability of travel routes, thus allowing for greater ability to practice traditional land use.

The collaborative-geomatics informatics tool would allow for the support of social networks where real-time travel information in the form of mapped trails/commentary/picture/videos can be posted online, allowing for further networking and discussion. The sharing of information via social networks can further help to rapidly mobilize community response in times of crisis [38]. Indeed, Pennesi et al. noted that one of the main barriers toward climate change adaptation in the arctic was the lack of social networks to support the informed decision on the safety of land-based activities [74]. Historically, community and family units played an important role in supporting adaptive capacity in northern indigenous communities [38]. However, with changes to the social and cultural structures, many indigenous communities have seen radical changes in lifestyles, resulting in the erosion of the social networks that have historically supported adaptation to environmental challenges [38]. The building and support of social networks in arctic indigenous communities to build relationships of support and trust have been identified as key components in contributing to adaptability [38]. The collaborative-geomatics informatics tool has the potential to support the use of multiple social networks, where users can invite others to join a group and share specific information with those members.

Thus, the collaborative-geomatics informatics tool has the potential to increase the adaptive capacity of arctic–subarctic indigenous communities by supporting the transfer of TEK (**Table 1**). The transfer of information can be horizontal across age groups and/or vertical between age groups [57, 64]. Adaptive capacity has been described as “a set of resources that represent an asset base from which adaptations can be made” [41]. TEK plays a pivotal role in the manifestation of adaptive capacity and is considered to be a vital component in the effectiveness of adaptive strategies [5, 41, 57, 74].

Features of the informatics tool	Importance
Geospatial information (oral, written, visual [picture/video])	• Ability to store geospatial information on culturally important locations, such as bush trails [64, 43] • Linking youth and elders through technology and traditional knowledge in the form of oral history [43]
Social networking (groups and forum development)	• Allows for social networking to help decrease the risks associated with heading out onto the land • Formation of groups and forums within the geomatics tool to share information and discuss experiences [43] • Communication can foster the collaboration and exchange of information between individuals and communities along the coast that share resources and travel routes [38]
Real-time capabilities	• Real-time travel information will allow families and community members to determine the safest time to travel and empower youth to travel onto the land • Greater safety can allow for more travel between communities and the resulting transfer of knowledge • Real-time capabilities can help with the selection of the safest travel route going out on the land

Table 1. Key features of the collaborative-geomatics informatics tool important for the monitoring of unsafe travel routes.

Access to TEK is important in the formation of appropriate adaptive responses that together support the building of adaptive capacity. The effectiveness and strength of an adaptive measure is directly related to the quality of information available [42]. Individuals and communities that readily have access to TEK will possess the depth of knowledge required to develop strong adaptive responses toward hazardous and unpredictable travel routes. Three areas of adaptive responses, *flexibility, hazard avoidance*, and *emergency preparedness*, have been identified as being important in building adaptive capacity in the arctic [4, 42]. The collaborative-geomatics informatics tool has the ability to support each of these adaptive responses.

The diversity and flexibility in travel routes and resources are vital in the adaptability toward unpredictable climate events and dangerous travel conditions [38]. The collaborative-geomatics informatics tool imbues flexibility, by allowing for modification and adjustments to travel routes prior to heading out onto the land. Based on real-time trail and road conditions, decisions can be made with respect to changes in the modes of transportation, harvesting equipment, and location of harvesting activities [41, 75]. Flexibility and diversity in behavior lead to the development of new skills and knowledge, which can further support the ability to make flexible and diverse decisions, resulting in increased adaptive capacity. There are some constraints to behavioral flexibility that can be addressed through features of the collaborative-geomatics informatics tool. Income constraints have been shown to restrict the flexibility and diversity of behaviors [75]. Changes in the mode of transportation and type of harvesting equipment are resource-dependent and can act as barriers to adaptation. Social networking, such as discussion forums and group settings, supported by the informatics tool, can link community members together to share resources, exchange ideas, and develop groups that could pool their resources and travel together.

Hazard avoidance of dangerous and unsafe travel routes is another adaptive response important to the development of increased adaptive capacity. Technology has been shown to play an important role in the avoidance of hazards [41]. Geospatial information provided in the informatics tool acts as a knowledge base from which individuals and groups can accurately identify real-time hazardous locations and determine the safest way to travel or whether to travel at all. Photographs and videos uploaded onto the tool can also provide valuable in-depth detail and real-time travel information of hazards to be consulted prior to heading out onto the land. The real-time capabilities of the informatics tool can also support more efficient maintenance and repair of hazardous locations on travel routes. Geospatial information uploaded onto the tool can inform ice-road maintenance crews of the exact locations of hazardous conditions, allowing for quicker and more efficient resource use.

When facing unpredictable environmental conditions, emergency preparedness is an important adaptive response. Anticipating adverse travel conditions prior to traveling can help avoid dangerous and potentially deadly situations. The collaborative-geomatics informatics tool can serve as a decision-support tool that allows individuals and groups to make informed decisions on travel conditions before heading out. Some of these decisions are regarding the equipment and supplies required to travel safely. The modification of equipment used while on the land, such as more powerful boat engines and snowmobiles, can reduce the degree of exposure to dangerous situations [38]. The packing of extra and/or emergency supplies (e.g., extra gas, food, water, and warm clothing) is a proactive adaptive response to hazardous (or potentially hazardous) situations while traveling on the land. The informatics tool can help in emergency

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preparedness through proactive route planning. Individuals or groups heading out onto the land can geospatially mark locations on the tool, prior to heading out, to identify where they could be located if any issues were to arise. Furthermore, the social networking abilities of the tool can help to bring individuals together to form traveling groups, reducing the likelihood of emergencies and sharing of supplies to reduce the costs associated with bush travel. In this way, communities can build their adaptive capacity to deal with an unpredictable environment.

A dimension of adaptive capacity is the ability for a community to be innovative [46, 76]. Innovation can be defined as an "initiative, product, process, or program that profoundly changes the basic routines, resources, and authority flows or beliefs of any social system" [46, 76]. The collaborative-geomatics informatics tool can not only help reduce the degree of exposure to unsafe travel routes, but it can also allow communities to monitor, store, and analyze various forms of information to help monitor cumulative impacts of environmental change in the area. The ability of the informatics tool to nurture diversity and flexibility of different forms of knowledge is a key attribute to the development of innovation [46]. Increased innovation would allow for subarctic First Nations communities to not only adapt to climate-related impacts, but also actively engage in community-based land-use planning, increasing the community's ability to respond to change associated with the ever-increasing developmental pressures in the region [46].

3.3. Future development of the informatics tool

The next step in the development and implementation of this real-time informatics tool will be to work toward developing it as a mobile App supported by Apple iPhone®, iPad®, iPod®, and Andriod® phones. This would allow for the tracking and mapping of not only community travel routes, but also personal and family trails. With the development of a collaborative-geomatics informatics tool mobile App, the tracking of travel routes and the storage of TEK could be accomplished without the expense of having to purchase GPS tracking devices. Furthermore, due to privacy concerns around third party Apps, a mobile geomatics App would allow individuals to have control over their own information. Having a handheld informatics tool that could seamlessly track travel routes and automatically upload trails without the use of cables and computers would allow for greater accessibility by community members who might not have access to computers and the skills to use traditional GPS devices. Another added benefit of developing a handheld mobile version of the informatics tool would be using the tool for navigation. High-resolution base maps used in the current geomatics system, when loaded onto the tool prior to heading out onto the land, could act as a navigation tool to help guide individuals or groups around hazardous areas or during emergencies.

Although the monitoring and mapping of real-time safe-travel routes is a specific application, this collaborative-geomatics informatics tool could also be used for other purposes [64]. Once the collaborative-geomatics informatics tool has been fully community-tested and modified to meet the community's needs, the informatics tool will be given to the community, as a stand-alone secure system, at no cost to the community. It should be emphasized that this type of innovative approach and technology has the potential to help other indigenous communities in the Canadian arctic and subarctic, as well as indigenous communities located outside of Canada.

4. Conclusion

It is clear from numerous scientific studies that global air temperatures are rising at a rate never experienced before. This elevation in temperatures impacts Earth's ecosystems, resulting in changes in snowfall, rainfall, sea levels, and species distributions. Such environmental changes have been well documented, but there has been relatively little research into the impacts of climate change on social systems. As the global population continues to rise and the divide between the rich and poor widens, it is expected that climate change effects will disproportionately impact already marginalized populations. Furthermore, experts predict that northern latitudes will experience the greatest impacts of environmental change due to global warming. First Nations communities in Canada have a history of marginalization and social inequalities, especially in communities located in the northern regions of the country. Despite these differences, there has been relatively little done to mitigate the impacts of environmental change on indigenous people. The ability to travel on land, ice, snow, and by water to acquire resources is an integral part of many indigenous people's lifestyles. However, changes to the extent and extant of ice on lakes and rivers, changes in the quality and quantity of snow, increased precipitation especially in the form of freezing rain, and unpredictable storms have resulted in less predictable and more dangerous travel conditions, impacting not only the health and safety of individuals but also the traditional lifestyle that is vital to the cultural well-being of these indigenous communities.

This study set out to examine the potential of a novel decision-support tool to reduce the degree of exposure to unsafe travel routes for James Bay Cree. It is clear from this research that the collaborative-geomatics informatics tool developed by the University of Waterloo's Computer Systems Groups has the potential to allow for the community to monitor, in real-time, the safety of travel routes. The ability to monitor and store information, on the safety of travel routes, has the potential to promote adaptive capacity and aid in knowledge transfer within arctic and subarctic First Nations Cree communities. The use of TEK and Western science as complementary knowledge system should be encouraged [77]. Increased adaptive capacity can lead to social and ecological resilience, allowing indigenous communities to better withstand the shocks and stresses that further environmental change and future resource development will bring [70, 78, 79].

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