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A COMMUNITY-BASED APPROACH TO MAPPING GWICH'IN OBSERVATIONS OF ENVIRONMENTAL CHANGES IN THE LOWER PEEL RIVER WATERSHED, NT

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In Canada's western Arctic climate change is driving rapid ecological changes. Ongoing and locally-driven environmental monitoring, in which systematic observations of environmental conditions are recorded and synthesized, is required to understand and respond to climate change and other human impacts. Indigenous peoples' traditional ecological knowledge is increasingly used as the basis for regional monitoring, as there is a need for detailed, place-specific information that is consistent with local ways of understanding and interacting with the environment. In this project, participatory multimedia mapping was used with Teetł'it Gwich'in land users and youth from Fort McPherson, Northwest Territories, Canada to record information about local environmental conditions and changes. Gwich'in monitors made trips on the land to document environmental conditions and changes using geotagged photo and video observations. Subsequently, land users provided detailed information about each observation in follow-up interviews, which were added to a web-based map displaying participants' photos and videos. In this paper, we present the outcomes from the first year of research, explore the diverse types of knowledge this approach can contribute to environmental monitoring, and identify areas of convergence between traditional ecological knowledge and scientific research in the Arctic. Our work shows that this approach can make an important contribution to monitoring environmental changes associated with climate change in a way that is locally relevant and culturally appropriate.

Keywords: *traditional ecological knowledge, participatory mapping, climate change, environmental monitoring, Arctic, Gwich'in*

Introduction

The circumpolar Arctic is experiencing accelerated environmental changes due to rising air temperatures and increasing human development (ACIA 2004; Chapin et al. 2005; Stefansson Arctic Institute 2004). Recent changes include shifts in the frequency and magnitude of natural disturbances, changes to vegetation structure, permafrost degradation and altered soil chemistry, decreasing land stability, shifts in animal population size and distribution, and changing water levels and quality (Jorgenson et al. 2001; Kokelj et al. 2005, 2013; Lantz et al. 2009; Serreze et al. 2000; Sturm et al. 2005; Tape et al. 2006). These environmental changes immediately impact northern indigenous communities whose well-being and livelihoods are intimately linked to the health of the land (Chapin et al. 2006; Krupnik and Jolly 2002; Loovers 2010; Parlee et al. 2005). Northern land users are faced with climate conditions that are increasingly unpredictable,

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including new variations in freeze-thaw cycles of sea and inland ice and altered timing and duration of weather events, which have in turn driven unprecedented erosion patterns that can interfere with peoples' mobility and lifestyles (ACIA 2004; Stammler-Gossmann 2010). Concomitant economic, cultural, and technological changes also contribute to shifting social dynamics that influence how communities perceive and interact with their environment, and ultimately how vulnerable they are to climate change (Aporta and Higgs 2005; Ford and Smit 2004). In order for northern communities, researchers, and decision makers to manage and adapt to changing climate and environmental conditions, diverse information about the location, extent, and drivers of regional changes is needed (Berkes and Jolly 2002; Moller et al. 2004). In this paper, we describe a pilot community-based monitoring program designed with the Teetł'it Gwich'in of the lower Peel River watershed, Northwest Territories, Canada and explore its potential contributions as a locally responsive research approach.

Environmental monitoring to assess ecological changes is challenging in northern regions because remote logistics are complex and expensive (Artiola et al. 2004; Lovett et al. 2007; Wiersma 2004). In some areas, changes in land cover are occurring so rapidly that maintaining an accurate inventory represents an ongoing challenge (Kokelj et al. 2012). Monitoring programs can also be constrained in their scope and timeliness by a lack of local expertise, language and cultural barriers, and reliance on externally-based institutions (Berkes et al. 2001; Moller et al. 2004; Usher 2000). Moreover, climate change adaptation projects and environmental comanagement projects intended to help communities adapt and build resilience in the face of change often can be made less effective because of a failure to take into account local conditions and perceptions (Stammler-Gossmann 2010).

Research has shown that indigenous land users who spend significant time on the land are in a unique position to observe and monitor local environmental conditions and detect changes at an early stage (Davidson-Hunt and Berkes 2003; Gearheard et al. 2011; Hinkel et al. 2007; Hinzman et al. 2005; King et al. 2008; Kokelj et al. 2012; Krupnik and Jolly 2002; Moller et al. 2004). Local observations of the environment made by indigenous land users can be especially insightful when integrated with conventional approaches to environmental science because such observations are rooted in traditional ecological knowledge (TEK): ''a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings with one another and with the environment'' (Berkes 2000:7). Traditional ecological knowledge is embedded in the places and cultures from which it develops, and includes an intimate understanding of local ecological processes (Basso 1996; Berkes 2000). Consequently, environmental monitoring that is rooted in TEK can provide insight about subtle patterns and changes, and over longer time periods than many scientifically-based studies of environmental change (Riedlinger and Berkes 2001).

Many TEK systems incorporate explicit environmental monitoring activities (Berkes 2000). These include qualitative indicators of climate and environmental variation based on sight, sound, feel, smell, and taste (Moller et al. 2004; Turner and Berkes 2006) that often focus on unusual patterns and occurrences, rather than averages, and rely on the experience, understanding, and memory of the observer (Berkes and Folke 2002; Moller et al. 2004). In short, because TEK provides a different kind of environmental monitoring at local scales associated with traditions and memories that add time depth, ethnobiologists—and, increasingly, ecologists—recognize that local observations and TEK provide information that can increase the resilience of communities facing both social and ecological changes (Berkes and Jolly 2002; Chapin et al. 2004). In the Arctic, TEK has accordingly been the basis of both community-based and scientific investigations of environmental change (Kokelj et al. 2012; Luzar et al. 2011; Pulsifer et al. 2012; Riedlinger and Berkes 2001). While many elders and TEK holders are eager to share their insights and concerns with researchers and members of younger generations, recording TEK effectively and appropriately is a complex undertaking. It can be especially challenging to record and share information in a way that is respectful of knowledge holders and consistent with the holistic, place-specific nature of TEK (Chambers 2006; Gilmore and Eshbaugh 2011; Hardison and Bannister 2011; Moller et al. 2004; Stringer et al. 2006). Interactive multimedia web-based maps and databases are becoming popular ways to organize and share local and traditional ecological knowledge, and their flexibility allows for less structured and more collaborative data management (Aporta et al. 2014; Gilmore and Eshbaugh 2011; McLain et al. 2013; Pulsifer et al. 2012).

Study Area

In northwestern Canada, the Peel River flows northeast into the Mackenzie River, passing through tundra and taiga in the Yukon Territory and taiga and tundra in the Northwest Territories (Figure 1). Climate change and shifting environmental conditions in the lower Peel River watershed (including the terminal 75 km of the Peel River and its tributaries) are of concern to the Teetł'it Gwich'in community of Fort McPherson, Northwest Territories (Scott 2011). This is an area of continuous permafrost, except under lakes and rivers, where the active layer is rarely deeper than 1 m (Hughes et al. 1981). The climate is subarctic and is influenced by weather patterns from the Arctic Ocean (Hughes et al. 1981). Climate change and human activities are influencing water quantity and quality, wildlife and fish populations, disturbance regimes (e.g., landslides, river bank erosion, and fires), transportation and municipal infrastructure, and heritage sites (Kokelj et al. 2013; Scott 2011).

The Teetł'it Gwich'in Community

The Gwich'in (meaning ''one who dwells'') are an indigenous people whose territory extends from northeastern Alaska to the Mackenzie Delta of the Northwest Territories (Vuntut Gwitchin Nation and Smith 2010; Figure 1). The Gwich'in language is in the Athapaskan language family and Gwich'in have historically been referred to as Dene, Loucheux, Kutchin, Tukudh and Athapaskan (Osgood 1934). There are eight Gwich'in bands, including the Teetł'it Gwich'in (meaning ''people of the headwaters'' of the Peel River) (Vuntut Gwitchin Nation and Smith 2010). The Teetł'it Gwich'in have occupied the Peel River watershed for thousands of years, traveling seasonally on foot and with

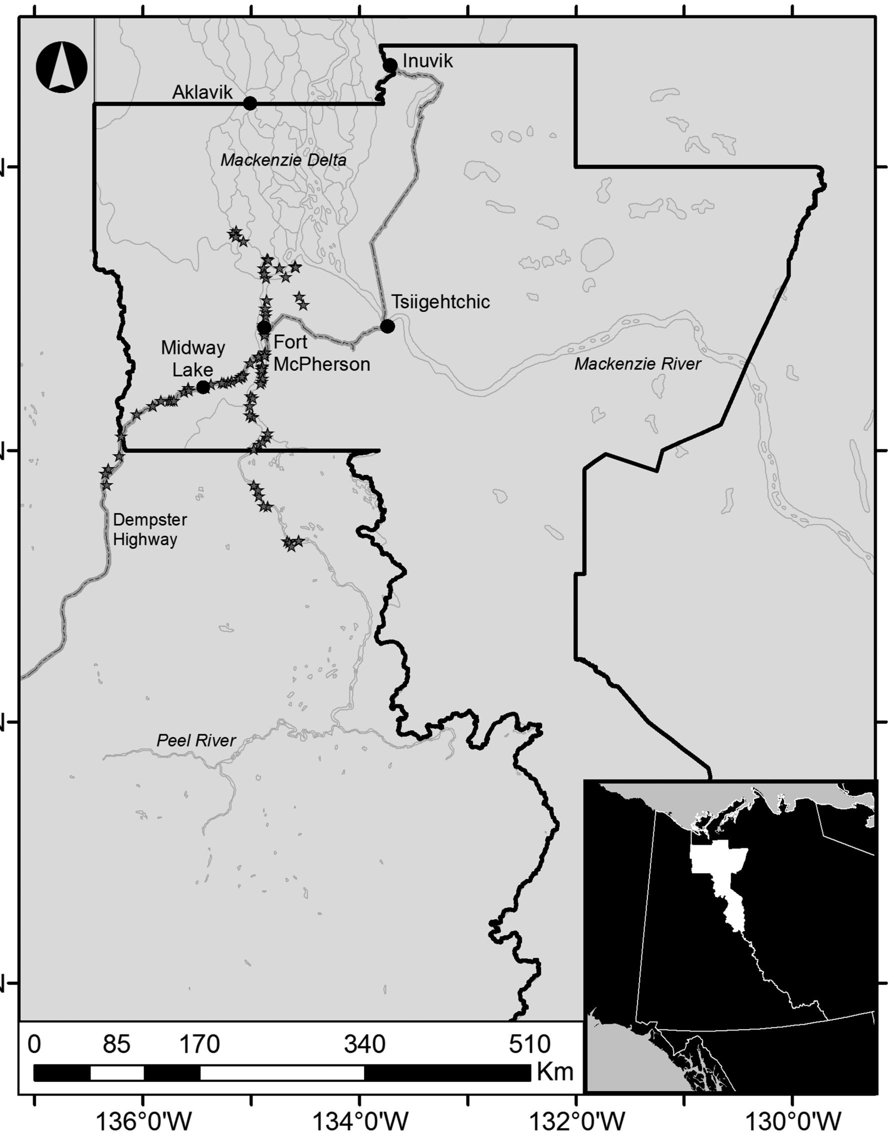

Figure 1. Distribution of 101 Gwich'in observations of environmental conditions and changes along the Dempster Highway and the lower Peel River and its tributaries in the Northwest Territories and Yukon recorded from May to September 2012. The Gwich'in Settlement Area (GSA) is framed by the solid black line. The inset map at the bottom right shows the location of the GSA in northwestern Canada.

birch bark canoes to hunt, trap, fish, and harvest foods, medicines, and materials and have an especially close relationship with caribou (Fafard and Kritsch 2005; Vuntut Gwitchin Nation and Smith 2010). Over generations, they developed an extensive network of trails, camps, and temporary settlements that continue to be used, with most families maintaining camps along the Peel River and its tributaries from the Mackenzie Delta to up the Peel River as far as the Yukon

(Loovers 2010). Today, the majority of Teetł'it Gwich'in reside in Fort McPherson, Northwest Territories (in Gwich'in, *Teetł'it Zheh*, meaning ''Head of the waters-town''), which originated as the first Hudson's Bay Company trading post erected in the Mackenzie Valley in 1840 and was moved to its present location 6 km down the Peel River in 1852 due to flooding (Fafard and Kritsch 2005). Fort McPherson is the largest Gwich'in community in the Northwest Territories, with a population of around 900. The modern economy is based on hunting, fishing, trapping, wage labor, and tourism (Scott 2011). Treaty negotiations between the Gwich'in Tribal Council, representing all Gwich'in communities in the Northwest Territories, the Government of Canada, and the Government of the Northwest Territories, began in the 1970s and culminated in the signing of The Gwich'in Comprehensive Land Claim Agreement in 1992 (AANDC 1992). This land claim delineates the Gwich'in Settlement Area including 56,935 km^2 of land in the Northwest Territories, and grants surface land ownership of 16,264 km^2, surface and subsurface land ownership of 6,065 km^2, and subsurface land ownership of 93 km^2 to the Gwich'in Tribal Council (AANDC 1992).

In recent years, Gwich'in knowledge has guided several community-based environmental monitoring projects. The Arctic Borderlands Ecological Knowledge Cooperative Project has employed community members to administer surveys and collect first-hand accounts of environmental observations and changes from Gwich'in and Inuvialuit communities in the Northwest Territories, Yukon, and Alaska since 1994 (Kofinas 1997; Robinson and Nguyen 2011). Teetł'it Gwich'in adults, elders, and youth have also participated in recent community climate change adaptation planning to identify areas of concern and provide recommendations for adaptation (Scott 2011). One limitation of these programs is that they have produced descriptions of changes that are not directly linked to specific places on the landscape. Since understanding and responding to the consequences of climate change and environmental impacts require detailed information, it is vital that ongoing monitoring include place-specific reporting.

Monitoring and responding to the impacts of global climatic change and disturbance requires regionally specific data that meet the needs of local communities. To address this need in the lower Peel River watershed, participatory multimedia mapping was used in a pilot monitoring program to document environmental conditions and changes associated with climate change and other natural and anthropogenic disturbances. We anticipated that this approach would provide diverse and richly detailed information about local social-ecological systems including the environmental and social impacts of environmental changes, how the Teetł'it Gwich'in community perceives and interacts with its environment, and how local communities can be empowered to share and gain knowledge in a way that is compatible with mainstream environmental monitoring programs (Gilmore and Young 2012).

Methods

Background

This project emerged from discussions between representatives of the Teetł'it Gwich'in community and scientists involved in a Northwest Territories

Cumulative Impact Monitoring Program (CIMP) research project examining massive permafrost disturbances in the lower Peel River watershed (Kokelj et al. 2013). During initial discussions at community research presentations and meetings with the Teetł'it Gwich'in Renewable Resource Council (TGRRC) and the Gwich'in Renewable Resources Board, community members prioritized the development of a community-based monitoring program based on Gwich'in perspectives and knowledge. In November 2011, CIMP researchers, Harneet Gill and Trevor Lantz, proposed a research model that had been used successfully in *Inuvialuit* communities (Bennett and Lantz 2014) and partnered with the Gwich'in Social and Cultural Institute (GSCI) (Executive Director Sharon Snowshoe and Research Director Ingrid Kritsch) to develop an environmental monitoring program using photography, videography, semi-structured interviews, and web-based mapping. The research approach was proposed by Gill and Lantz and developed with Snowshoe and Kritsch. Gill conducted field research and interviews, coded interviews and uploaded data to the website. Lantz and Gill analyzed interview data and managed website development. Snowshoe and Kritsch liaised with the community, provided logistical support, and verified data and analysis.

Protocol Development

At the outset of this project the authors decided to use participatory multimedia mapping (PMM), a process in which participants act as co-researchers to map information and knowledge using digital tools (such as digital cameras and audio recorders) and in-depth interviewing. Participatory multimedia mapping consists of three stages: 1) digital tools training; 2) on-the-land trips to make observations; and 3) follow-up interviews. Observations made by community members are then used to create a map representing the physical, social, and cognitive environment. Similar approaches have been used in many contexts to allow participants to express their own perspectives and voices (Clark 2011; Dennis et al. 2009; Sherren et al. 2010).

In March 2012, Gill and Lantz visited Fort McPherson to seek community input on project goals and methodology, and to identify potential participants. The proposed PMM methodology was presented and discussed with GSCI staff, elders participating in a GSCI place names mapping project (Aporta et al. 2014), members of the Fort McPherson Climate Change Adaptation Project (Scott 2011), and members of the Teetł'it Gwich'in Renewable Resource Council. These discussions produced two additional project goals: 1) contribute to knowledge-sharing and relationship-building between youth and experienced land users (members of the community with established TEK); and 2) provide youth with learning and experience with digital tools. The PMM protocol was thus designed to pair up youth participants with more experienced land users and involve youth in data collection through learning and use of digital tools. A test field trip in March 2012 with a land user recommended by the GSCI was followed by eight trips from May to September 2012, during which 12 participants used the protocol to make 101 observations. Trips lasted from a few hours to two days and routes were up to 70 km long. In March 2013, a steering committee with representatives from relevant community organizations was formed to review results from the first eight trips and provide ongoing feedback and direction on project methodology and outcomes.

Table 1. Teetł'it Gwich'in elders, land users and youth (N=12) who participated in participatory multimedia monitoring from May to September 2012.

Gwich'in participant	Gender	Role	Trips made
Abe Peterson	M	land user (elder)	1
Angela Alexie	F	youth	1
Ashley Kay	F	youth	2
Billy Wilson	M	land user	1
Christine Firth	F	land user	2
Clarence Alexie	M	land user	1 (not interviewed)
Dorothy Alexie	F	land user (elder)	1
Emma Kay	F	land user (elder)	2
Herbie Snowshoe	M	youth	2
Robert Alexie	M	land user (elder)	0 (interview only)
Wade Vaneltsi	M	youth	1
Wanda Pascal	F	land user	1

Participatory Multimedia Mapping

PMM was conducted by pairs of Gwich'in youth (under age 30) and experienced land users including elders. Potential participants were identified and contacted by the GSCI and Teetł'it Gwich'in Renewable Resource Council (Table 1). Land users were selected based on three criteria: 1) their extensive experience traveling and living on the land; 2) their thorough knowledge of environmental conditions and changes; and 3) their ability to comment on changes over time. Youth were selected based on their awareness of the environment, a desire to be on the land, and an interest in photography (Table 1). In a few cases participants decided to include extra people on the trip who were not directly involved in the research (e.g., hunting partners, family members). These latter individuals did not participate in trip planning, digital-tool training, or interviews. Some youth participated in more than one trip, and some trips included one youth paired with two land users, according to participants' preferences.

Land users decided where and what to observe, planned trip logistics, and shared their personal knowledge, experiences and observations. Youth participants documented land-based observations using photos, videos and GPS, and contributed to semi-structured interviews. As facilitator, Gill provided digital tools training, helped with trip logistics, took back-up photos and videos, conducted the follow-up interviews, and maintained the web-based map. Participants were compensated for their time through the *Teetł'it Gwich'in* Renewable Resource Council at local rates, and provided prior informed consent to participate and be acknowledged in the research results. A Traditional Knowledge Research Agreement was also signed between University of Victoria researchers and the GSCI. Although several land users were bilingual in Gwich'in and English, research was conducted in English because Gwich'in was not spoken fluently by youth participants. Land users provided Gwich'in translation and place names when they felt they were appropriate.

Trip Planning and Digital Tools Training

Once a land user and youth pair was formed, Gill met with them to discuss the project objectives and decide where and what to observe. Printed and online maps of the area were consulted to plan a trip lasting from a few hours to several days. Destinations in the pilot year were limited to areas accessible by vehicle via the Dempster Highway and by boat along the Peel River and tributaries (Figure 1). These destinations were chosen because they are along the most frequently traveled routes, and the cost of travel to more remote destinations would have significantly reduced the number of possible trips and participants. Following the initial meeting, youth participants were given an orientation to digital tools, which included a waterproof point-and-shoot digital camera (Olympus Tough TG-820), a digital bridge camera (fixed lens with wide zoom range; Fujifilm Finepix s2980), a digital single-lens reflex (SLR) camera (Nikon D700), an audio recorder (Zoom Handy Recorder H2), and a GPS unit (Garmin GPSmap 60CSx). The youth selected his or her preferred camera and received more detailed instructions followed by practice taking photos and videos. When the youth selected the SLR camera, he or she was trained to adjust exposure manually by changing shutter speed, aperture, and ISO (the sensitivity of the image sensor to light). While on the trip, the facilitator gave youth tips on how to compose photos, create effects, and care for the cameras.

On the Land Media Capture

In addition to pre-planned observations chosen by the land user during the trip planning meeting, each trip typically included impromptu stops. At each location, the youth and the facilitator took photographs and sometimes recorded videos, while the group chatted informally about what was being encountered (Figure 2). To avoid interrupting or inhibiting the discussion and photography by requiring participants to be stationary and ''on the record,'' these conversations were not recorded. However, field notes were made to use as prompts during follow-up interviews. A GPS unit was used to record a tracklog of the trip, which allowed each observation to be georeferenced by matching the media time codes to the tracklog timecode using geolocation software (RoboGeo).

In-Depth Semi-Structured Interviews

After each trip, a time for a follow-up interview in Fort McPherson within two days of the trip was arranged. In advance of each interview all trip pictures and videos were loaded onto a computer, and participants chose the clearest and most representative photos or videos from each site. These media were used to guide an audio-recorded, semi-structured interview with the land user and youth. As they looked at the photos or videos from each site, land users were asked to describe what was present, where it was, and why it was important. They were also asked to describe how the site had changed, and how it affected individuals and the community. After the first few observations, land users would often begin descriptions without prompts, and follow-up questions were used to seek elaboration and clarification. Youth participants listened and contributed as opportunities arose.

Online Mapping of Observations

To organize and present participant observations, Gill and Lantz used a Drupal-based web platform called Community Knowledge Keeper (Kwusen 2012). Participants reviewed and approved their interview transcripts and media in March 2013 before they were added to the site. Site administration is currently

Figure 2. Photographs taken during participatory multimedia mapping of environmental conditions in the lower Peel River watershed, Northwest Territories: (A) Herbie Snowshoe using video to document ice conditions on the Peel River (May 2012, photo by Christine Firth); (B) Wanda Pascal and Emma Kay observing and collecting Labrador tea near the Yukon-Northwest Territories border (September 2012, photo by Herbie Snowshoe); (C) erosion of the Dempster Highway associated with

managed by University of Victoria and any member of the public can request a username and password for access. Observations added to the project website are organized by trip, location, participant, and topic. After logging in, map users are directed to an overview of the multimedia monitoring project (see Supplemental Material for layout of pages, or refer to the website at http://gwichin.kwusen.com). Viewers can explore a map with all observations made to date, and navigate separate lists of trips, observations, participants, topics, and species affected. Individual entries on these lists can be clicked to display more information. Trip pages provide details about the trip, a list of participants, a map and list of observations, an interview audio file, an interview transcript, and all photos and videos taken on that trip. Observation pages provide a map of the location, list the observer, date and time, and provide photos, videos, interview audio clips, transcripts, and additional media and notes pertaining to that observation. Each observation is also tagged with one or more topics according to the type of environmental phenomenon and knowledge it contains. Participant pages display a photo, biographical details, and in some cases a written or recorded comment on their experience doing this research.

A long-term goal of this project is to develop local capacity to monitor and respond to environmental changes. The PMM website is currently in development phase which requires consultation from technological experts (Kwusen Research and Media). However, the authors anticipate that once website settings are finalized, community-based data input and maintenance will be feasible because the website is being designed to be user-friendly.

Data Organization and Analysis

To facilitate online mapping of observations, interviews were coded to identify individual observations, and each observation was labelled with a primary theme and a sub-theme (Table 2). Each observation consists of a photo and/or video, an interview audio and transcript clip, and a map location. Themes were used to organize information into broad categories such as vegetation or development, whereas sub-themes generally reflected the reason why the site was visited, such as an incidence of shrub increase or a specific gravel quarry. Each observation was also given a brief description, name and site code. To summarize the nature of environmental changes and explore the types of knowledge and insights generated by the PMM approach, Gill identified all types of information and emergent themes in interviews by coding them using NVivo. Gill and Lantz used both NVivo and MS Excel to explore the

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retrogressive thaw slump activity (September 2012, photo by Wade Vaneltsi); (D) a retrogressive thaw slump in the Peel Plateau (August 2012, photo by Ashley Kay); (E) riverbank erosion affecting a fish camp on Husky Channel (June 2012, photo by Angela Alexie); (F) reviewing the use of a GPS-equipped camera with youth Anthony Wilson before a trip down the Peel River with Abe Wilson (August 2013, photo by James Wilson); (G) Emma Kay observing and collecting mushrooms for tinder at Nitainlaii Territorial Park (September 2012, photo by Harneet Gill); and (H) Herbie Snowshoe photographing berry conditions at the Yukon-Northwest Territories border (August 2012, photo by Harneet Gill).

Table 2. Themes and sub-themes for Gwich'in observations of environmental conditions and changes, indicating the primary reason an observation was made.

Theme	No. of observations	Sub-theme	No. of observations
Environmental conditions	47	Riverbank erosion	21
		Melting permafrost	8
		Riverbank conditions	4
		Mud/sandbars	2
		Altered stream	2
		Water levels	2
		Ice conditions	2
		Changing environmental conditions	1
		Altered lake	1
		Drained lake	1
		Melting snow	1
		Water availability	1
		Weather	1
Traditional and cultural use	26	Culturally important place	17
		Berry harvesting	5
		Harvesting site	1
		Place of observation and hunting	1
		Travel route	1
		Water levels	1
Vegetation	8	Bigger trees	3
		Increased willows	3
		Increased shrubs	1
		Dead willows	1
Development	6	Gravel quarry	5
		Dempster Highway	1
Wildlife	3	Wildlife populations	1
		Wildlife habitat	1
		Traditional food	1
Knowledge transfer	1	Knowledge sharing	1

relationships between categories of knowledge and meaning from the perspective of Gwich'in participants, with consultation with Snowshoe and Kritsch.

Results

In the pilot year of this project, eight land users and four youth recorded their observations of environmental conditions and changes (Table 1). A total of eight trips were made out of Fort McPherson, and 101 observations were recorded (Figure 1). Trips were limited to areas that could be accessed by boat on the Peel River and its tributaries, or by truck on the Dempster Highway. The majority of sites selected by participants were chosen to exemplify environmental conditions and traditional and cultural use sites (Table 2). The most common environmental observation was of erosion and melting permafrost driven by recent changes in climate (Table 2). Retrogressive thaw slumping has become more common in the upland area southwest of Fort McPherson in recent decades (Kokelj et al. 2013). These dramatic changes, often involving large sections of earth caving in or rows of trees falling into lakes and streams, were noted by many observers (Figure 2). Observations of culturally important places included both man-made (e.g., a fish camp) and natural (e.g., a red ochre deposit) landscape features (Figure 2).

In follow-up interviews, land users provided detailed information about the physical nature of each environmental observation, including temporal and spatial dimensions, magnitude of change, and physical characteristics. Phenomena that occur over time, such as erosion, plant growth, and weather events, were described in terms of initiation time, duration, rate, seasonal timing, and frequency, and were often compared to what land users conceive of as normal or unusual patterns. Time was expressed using specific dates and durations (days, weeks, etc.) or in reference to other events. The physical dimensions and locations of events, phenomena, and landscape features were often described subjectively and involved analogies and personal references. For example, to describe how much larger willows have become around the Peel River ferry crossing, Emma Kay remembered, ''in the [19]70s they were small little willows. If somebody set tent right in the middle you just could see them walking around. From their waist up, or even half the legs, that's how small they were in the '70s, '80s, like that.''

In addition to describing environmental conditions and changes, participants shared their knowledge of the social and ecological causes of, and interactions among, the phenomena observed. For example, when asked why more sandbars have been forming in the Peel River, Abe Peterson gave an explanation based on his knowledge of environmental processes: ''see, what is happening, the current is so low, there's hardly any current. Dead water. And that's when the sand don't move, it just stays there.'' Conversely, Emma Kay explained changes in weather by referring to cultural teachings, explaining that ''Elders from way back, they tell us everything (on the land) is going to change.''

Climate change was referenced as an example of how environmental conditions have changed and was cited to explain why other environmental changes had occurred—all four elders recounted how much colder average and minimum temperatures used to be when they were growing up. These comments were made while discussing changing environmental conditions in general and how they affect individuals. As Emma Kay recounted, ''We're not used to heat. Cause we were brought up, when we were kids, we were brought up 60, 70 below. Now today we sit in the shade'' because temperatures are warmer year-round.

Climate change was often cited indirectly (i.e., referring to more or too much heat or warmth) or directly as a driver of observed environmental changes. The combination of warmer air temperatures and heavy rainfall events was highlighted as a cause of permafrost melting and resultant riverbank erosion and lake drainage: Robert Alexie explained that mud slides occur when there is ''too much rain, and [when it is] too hot.''

Participants' observations also focused on the social and ecological implications of environmental changes, and frequently included predictions about future conditions. Land users provided insights into the significance of these changes for individuals and the community, including both negative and positive outcomes. Consequences associated with environmental changes ranged from practical considerations to community-wide repercussions, as Billy Wilson explained, ''you don't travel one year, and [willows are] already growing too fast.

Some people just leave it; they can't even see their portage trails. So it kind of discourages people from basically going back to their camp, lot of deserted camps up here. People don't go out anymore.''

Land users also expressed concerns about the effects of environmental change and development on human health and safety, and suggested questions that should be investigated. For example, observing a stream that had changed from clear to muddy brown, elder Dorothy Alexie recommended, ''It would be really good to find out, you know. What's in that water. It's got to be something very powerful in it.''

While Gwich'in land users expressed apprehension and uncertainty about environmental challenges, their ideas and efforts also reflected the community's capacity for adaptation and flexibility. Novel ways to accomplish tasks and interact with the land emerged during our trips, and participants learned from each other throughout the process. For example, when the Peel River jammed up with ice, Christine Firth exclaimed after watching Abe Peterson navigate his boat through the ice, ''it was good to know that we could get out of there, like I've never in my life did this, but now I know I could get out of ice jams as long as it's high water.''

Interviews also revealed how knowledge about the environment is learned and passed on within and between generations. Participants explained that common sources of knowledge included direct observations and experiences on the land with more experienced people, as well as stories and conversations with other community members, especially elders. Wanda Pascal recalled, for example, that she knew of a good berry patch because ''last year, I seen Sarah Jerome and her sisters picking there for about four days […] so I scanned around there, and now I know how much berries is there.''

Gwich'in ways of expression were also preserved through the use of original transcripts, audio recordings and videos for each observation. Gwich'in speakers often made their points in a non-linear fashion and left key pieces of information unsaid, which might be found several minutes earlier in the conversation, or might rely on a presupposed knowledge of the community and territory. Consequently, the complete transcript, the details of the overall trip, and other observation topics, which are available from the trip page on the website, are needed to contextualize observations. Gwich'in words and place names were also important components of TEK shared through the observations of some land users, who frequently provided place names and provided translations and background information.

Places where observations were made often had special significance or value because of personal or shared history there. Participants often shared details about their own lives and families, exhibiting how culture and knowledge are tied to place (Basso 1996). These observations also provide considerable insight into Gwich'in history, land use, and how changing environmental conditions impact their daily life:

> I've been here since I was five years old. I remember playing on this little lake here, I remember being up at that Fish Hole, that's way up in the mountains. I remember my dad, that's what I remember. – Billy Wilson

Overall, the diversity of knowledge elicited through the PMM process during travels and interviews provides a rich and nuanced description of the processes that have shaped current environmental conditions, which can help understand and predict the social and ecological effects of climate and environmental changes.

Discussion

The knowledge and perspectives documented in this project highlight the vital role of TEK in efforts to understand and respond to environmental change in the Arctic, including the impacts of climate change on regional landscapes. By recording the specific impacts climate change has had on local ecosystems and communities, the map of environmental observations produced through PMM will be useful to communities and researchers seeking to monitor and respond to changing conditions. The combination of precise locations, photos, videos, and interviews provides qualitative and quantitative information about the nature, causes, and consequences of environmental changes and conditions associated with climate change.

This information is useful to the Teetł'it Gwich'in community because it will allow people to compare and confirm their knowledge about specific places, and gain new knowledge of changes, practices, and perspectives from different people. This may be especially useful for people who are not able to be on the land frequently, because it can allow them to learn from more experienced members of the community. For example, map viewers can see a video of Abe Peterson navigating his boat through willows during an ice jam, and learn how to overcome travel barriers from his experience. By searching topics such as dangers and infrastructure damage, map users can also identify areas that might require additional vigilance, investigation, or intervention. Because many of the changes observed in the lower Peel River watershed are likely related to global climate change, they will also be relevant to other communities throughout the Arctic.

Our experiences in this project show that an experiential and inclusive approach to community-based environmental monitoring can also unlock other aspects of TEK. These include social processes such as knowledge transmission, personal histories, and local understandings and expressions of knowledge. Attributing observations to specific participants respects the highly contextual and individual nature of TEK, while presenting all observations in the same map reflects the extent to which TEK is shared by a cultural group (Wenzel 1999).

A participatory approach to multimedia mapping is able to capture both the ecological and social impacts of climate change and environmental disturbances; participant descriptions of environmental changes were always a blend of environmental and social considerations, reflecting the inextricable connections between Gwich'in identity and the land (Loovers 2010; Parlee et al. 2005). Map viewers, whether they are Gwich'in or are unfamiliar with Gwich'in culture, can learn not only about how the environment is changing, but also about Gwich'in identity, history, language and activities. The primacy of Gwich'in voices in the map makes it easier to understand by members of the same culture, and is instructive for members of other cultures who are working in Gwich'in territory and want to improve their understanding of the social-ecological system in which environmental changes are occurring.

A holistic presentation of TEK from the perspective of the cultural insider preserves links between environmental knowledge and its cultural context, which facilitates interpretation (Berkes 2000). A more nuanced understanding of Gwich'in perspectives of the changing environment will encourage researchers and regional decision makers to be sensitive to local community concerns and interests. For researchers and decision makers inside and outside the community, the data contained in this project map can be used to develop hypotheses about how people will react to ecological variability, highlight areas of traditional use, and identify areas of special concern in reference to environmental conditions that require action (examples in McLain et al. 2013). The outcomes of this project, as well as feedback from participants and community partners, indicate that digital multimedia can be used to effectively record traditional ecological knowledge in a way that is consistent with Gwich'in culture and contemporary life. The insights documented will also be useful in regional climate change adaptation strategies, where large-scale climate change impacts must be understood and responded to in terms of local consequences and local capacity for adaptation (ACIA 2004; Scott 2011).

Involving and empowering youth was a key project goal identified by the community. Additionally, a lack of opportunities for youth and young adults to be on the land was identified by several land users as a problem that the project helped address. Monitoring trips provided opportunities for youth to participate in both traditional land-based activities and research. Our trips were not highly structured, and land users often included breaks to warm up by a fire, have a snack or meal, or harvest traditional foods. Youth volunteered or were encouraged to pick berries, shoot ducks, build fires, chop wood, and camp on the land with the guidance of more experienced land users. Abe Peterson explained that ''there's a lot of boys want to go out in the bush you know, they got no kicker [motor], no boat, no skidoo you know they just can't get out.''

In the course of each research trip, youth spent several hours with experienced land users, learning through observation, conversation, and practice. Although youth were not able to provide expertise, they contributed to the results of the study by asking questions on trips and in interviews and by sharing their own perspectives and stories about the places they visited:

> I really liked this project that you were doing 'cause it shows me a lot about our land and what's happening to it, and what started here even before I was born […]. I learned a lot actually just from going, doing this one day trip, it was, learned a lot about our land. And about our highways and what they do to keep our highway there and running and everything, that's pretty awesome. And especially taking pictures, 'cause I like taking pictures. – Ashley Kay

In addition to being a monitoring platform in its own right, the map of environmental changes produced through PMM can contribute to other environmental and climate monitoring initiatives. Qualitative data, particularly visual data, captured on the land by indigenous land users provide context-rich information about local environmental changes that can inform the interpretation of quantitative data (Bonny and Berkes 2008; Comiso et al. 1991). The participant-driven nature of the PMM approach also ensures that alternative perspectives and knowledge that may not seem directly related to environmental change are included in research. This allows communities to identify research parameters, often social, which would not likely be included in scientific research (Riedlinger and Berkes 2001). For example, Billy Wilson's observation that fewer people are going to their camps reveals an indicator that can be used to monitor land use and accessibility. Because the TEK presented is location-specific and integrates both social and ecological perspectives, it is likely to be useful in environmental management and planning (McLain et al. 2013).

The use of TEK in long-term, community-based monitoring is compatible with scientific monitoring and can lead to a more nuanced and thorough understanding of the drivers and consequences of changing environments (Riedlinger and Berkes 2001). As a result, the map produced in this project may also provide a useful platform for direct collaboration between community-based monitoring and scientific monitoring initiatives. Participatory multimedia mapping makes TEK-based monitoring data accessible to both communities and scientists. By preserving the scale and place-based nature of TEK, specific comparisons with scientific observations are possible (Gagnon and Berteaux 2009), yet TEK-holders involved in research are unconstrained by scientific research agendas since monitoring parameters are community-driven. The spatial and visual representation of TEK lends itself to being presented alongside scientific information with equal weight, and framing individual studies and observations as part of a wider data management system helps emphasize the parallels between traditional resource management systems and Western science-based management systems (Berkes 2009; Lertzman 2009).

A number of recent collaborations between TEK holders and researchers in Arctic indigenous communities have involved web-mapping. Participatory multimedia mapping has been used and evaluated favorably in *Inuvialuit* communities (Bennett and Lantz 2014). Customized GPS technology has also been used by Inuit hunters to record their observations while traveling on the land by snowmobile (Gearheard et al. 2011). A key strength of PMM is that it allows participants to take ownership over the process and results, which, in turn, empowers communities and builds local capacity by providing opportunities for research training and experience (Gilmore and Young 2012).

Data management is a critical issue for GPS-based research, and can represent a critical obstacle for community ownership of the research process and the data because of the expertise required. In this project, long-term data stewardship will require the ability to use the website interface, word processing software, data management software, photo and video editing software, transcription software, and GIS software. Other challenges include obtaining funding for training and job creation, creating a data backup strategy, and integrating the program with existing initiatives and community priorities. We anticipate that the partnerships that have already been established between the GSCI, University of Victoria and NWT CIMP will continue to play a role in building capacity and furthering community-based monitoring. Because PMM has the potential to elicit sensitive information and put it in the public domain, the management and access to data will also be a key issue to negotiate before the protocol becomes more widely used. Although any member of the public is able to access the website, doing so requires a username and password issued by the administrator (currently the University of Victoria Ethnoecology Lab). To control information sharing in the future, website settings can be customized for specific user groups.

This project is part of a partnership between academic (University of Victoria), community (GSCI), and government (AANDC) organizations, and ongoing collaboration will help ensure continuity of the project and applications for the outcomes of research. Follow-up research and local capacity-building and engagement by future researchers, graduate students, and research assistants affiliated with project partners will contribute to the long-term sustainability of this project. To facilitate community monitoring of environmental changes as a community-driven effort that does not depend on the facilitation of externally-based researchers, Gill and Lantz developed a protocol that will continue to operate out of the TGRRC office in Fort McPherson. As of September 2013, two GPS-equipped digital cameras were available for sign-out, along with travel compensation to overcome financial barriers to participation. The easy-to-use cameras and protocol instruction sheet ensure that land users will integrate monitoring with their regular travels on the land. As the cameras are returned, the geotagged photos and videos will be sent to the Ethnoecology Lab at University of Victoria, where they will be added to the web-based map that documents ongoing environmental monitoring.

Bringing together community members and researchers as equal participants in research builds familiarity and trust between facilitators and participants. More importantly, placing decisions about how research is conducted and communicated in the community's hands helps avoid replicating power imbalances that tend to exist between Western knowledge and TEK (Nadasdy 1999). Presenting knowledge collected in the images and words of knowledge holders in an accessible website also ensures results are returned to the community in an appropriate way (Chambers 2006; Gilmore and Eshbaugh 2011). The participatory research approach is inclusive and places the focus on local research priorities and perspectives (Wiber et al. 2004). Multimedia mapping also produces information about environmental conditions and changes that is highly descriptive, context-rich, and culturally rooted. This approach to research is culturally coherent as it relies on land-based activities that are integrated with community members' everyday lives (Bennett and Lantz 2014; Chambers 2006; Gearheard et al. 2011; McLain et al. 2013).

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