Polar Knowledge Canada
Savoir polaire Canada

POLAR
POLAIRE

POLAR KNOWLEDGE

Aqhaliat

REPORT 2018

Canada

For more information about Polar Knowledge Canada, or for additional copies of this report, contact:

Polar Knowledge Canada
170 Laurier Avenue West
2nd floor, Suite 200
Ottawa, Ontario K1P 5V5
e-mail: info@polar.gc.ca
tel.: 1-877-221-6213
fax: 613-947-2410

Twitter:
@POLARCanada

Instagram:
polar.knowledge

Facebook:
Polar Knowledge Canada

Website: https://www.canada.ca/en/polar-knowledge/aqhaliat.html)

Cet ouvrage est publié en français sous le titre :
Le rapport savoir polaire : Aqhaliat

POLAR
POLAIRE

Polar Knowledge: Aqhaliat Report

ISSN 2562-6078

Table of Contents

Table of Contents

LICHENS IN HIGH ARCTIC ECOSYSTEMS:

Recommended research directions for assessing diversity and function near the Canadian High Arctic Research Station, Cambridge Bay, Nunavut

Ian D. Hogg[1*], Leo G. Sancho[2], Roman Türk[3], Don A. Cowan[4], and T. G. Allan Green[2,5]

[1] *Canadian High Arctic Research Station, Polar Knowledge Canada, Cambridge Bay, Nunavut, Canada*

[2] *Unidad de Botánica, Facultad de Farmacia, Universidad Complutense de Madrid, Madrid, Spain*

[3] *University of Salzburg, Salzburg, Austria*

[4] *Centre for Microbiology, Ecology and Genomics, University of Pretoria, Pretoria, South Africa*

[5] *School of Science, University of Waikato, Hamilton, New Zealand*

* *ian.hogg@polar.gc.ca*

Abstract

Lichens are an important component of Arctic terrestrial ecosystems. An assessment by lichen researchers with polar and alpine experience has confirmed the dominant presence of lichens in and around Ikaluktutiak (Cambridge Bay). Three main lichen communities were found: (1) lichens growing among higher plants in wetter areas, (2) lichens growing on rocks and stones in drier sites, and (3) lichens forming soil crusts. To further enhance knowledge of lichens near Cambridge Bay, efforts should be directed towards identifying lichen species in the vicinity of the Canadian High Arctic Research Station (CHARS) and developing methods to assist non-experts with identification. Setting up a Herbarium at the CHARS campus and building a DNA barcode library will facilitate the use of molecular identification techniques. Determining growth rates of lichens will allow surface dating (e.g., age determination of archaeological sites) as well as the monitoring of environmental changes. Local lichen communities should be described and factors controlling their position on the landscape determined. Chlorophyll fluorescence techniques will allow non-contact determination of the length of active period, and timing of activity during the year. This, together with studies on photosynthesis, will allow performance of key species to be made, the influences of major environmental factors to be determined, and the carbon contribution to the communities to be calculated. Collectively, these data will assist in predicting the effects of climate change for High Arctic ecosystems. The location and excellent facilities of CHARS are ideal to underpin these studies and fill a major knowledge gap about tundra ecosystems in Arctic Canada.

Introduction

Lichens are an important component of High Arctic terrestrial ecosystems and provide a valuable food source for caribou, muskox and Arctic hare (Edwards et al. 1960, Thomas et al. 1994). Lichens are a unique complex of two types of organisms, an alga and a fungus, growing together in a symbiotic relationship; they require liquid water (rain, meltwater) to grow. Lichens are very common

Suggested citation:

Hogg, I.D., Sancho, L.G., Türk, R., Cowan, D.A., and Green, T.G.A. 2018. Lichens in High Arctic ecosystems: Recommended research directions for assessing diversity and function near the Canadian High Arctic Research Station, Cambridge Bay, Nunavut. Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 1–8. DOI: 10.35298/pkc.2018.01*

around the hamlet of Ikaluktutiak (Cambridge Bay) and are often the dominant vegetation type. They also have a potentially high diversity in the vicinity of Cambridge Bay owing to low precipitation levels (< 140 mm with 50% as summer rain) and limited competition with other vegetation types such as trees and shrubs. However, very little is known of their diversity in the High Arctic owing to difficulties in identification as well as access to study sites.

Recognized international lichen researchers were invited by Polar Knowledge Canada to provide an initial assessment of lichen communities near Cambridge Bay. The invitees all had extensive experience in Antarctic, alpine, and Arctic environments and have previously conducted research on the taxonomy, ecophysiology, growth, and ecology of lichens. As part of this present report, the researchers were tasked with providing recommendations to improve knowledge of lichen diversity and function in the Canadian Arctic.

Present situation: The Canadian High Arctic Research Station (CHARS) is expected to be fully operational in 2019 with an ongoing research program. Its primary objective is to “mobilize Arctic science and technology” and become “a world-class monitoring site that will act as a *hub* for CAMPNet (Canadian Arctic Monitoring and Prediction).” Towards this objective, CHARS has established an Experimental and Reference Area in which detailed research is possible on marine, freshwater and terrestrial ecosystems (CHARS 2015). Another key objective is to support the effective stewardship of Canada’s Arctic lands, waters, and resources. A mechanism to achieve this will be to “identify and target international and national partnership opportunities” (CHARS 2015). CHARS has recognized that, at present, little is known of the lichens in the vicinity of Cambridge Bay. However, recent research has focused on vegetation description and classification of higher plants using satellite technology and ground-truthing (CHARS 2015, Meidinger et al. 2015, McLennan et al. 2018). This is a highly appropriate approach for the region in which surface travel can be challenging, particularly in summer.

A feature of High Arctic vegetation is the large proportion of mosses and lichens, the latter particularly in drier sites, although little has been published for the Cambridge Bay region. One paper exists on lichens (Thomson and Weber, 1992), which lists 103 species, and another on bryophytes (Persson and Holmen, 1961), which lists 56 species (7 Hepaticae *liverworts*, 0 Sphagnales and 49 Bryales, *true mosses*). The low number of Hepaticae and absence of Sphagnales provide an indication of the extreme conditions (low temperatures and low rainfall) of the Cambridge Bay climate. However, species identification for both taxonomic groups can be problematic for researchers who have not specialized in these groups. Research into bryophytes is currently underway (J. Doubt, Canadian Museum of Nature; C. La Farge, University of Alberta). When it is considered that the two published studies were the result of brief (less-than-two-day) visits to Cambridge Bay, it is reasonable to assume that future in-depth collecting will greatly increase the number of species of both bryophytes and lichens.

The objective of this current work is to visit a range of sites in the vicinity of CHARS to collect lichen samples for identification, make an initial (non-quantitative) assessment of the main lichen communities and suggest possibilities for future research. Ongoing work will involve collaborations with existing national and international experts as well as with local communities. A primary aim will be to build the required knowledge and research skills at CHARS and in the north more generally. This will be done in conjunction with northerners so that the outputs of existing investments can be further enhanced.

Fieldwork

The fieldwork was undertaken from 14 July 2018 to 2 August 2018 using helicopter or ground support for sites within about 250 km of Cambridge Bay. Visits were made to sites in the vicinity of the CHARS campus (Cambridge Bay) and more widely in southern Victoria Island, particularly around Wellington Bay (Fig. 1). A full list of sampling sites and GPS locations is provided in Table 1. In all cases, site visits lasted from one to two hours with qualitative sampling carried out.

All samples were returned to the CHARS campus, where duplicates were made where identification in home laboratories was necessary. More than 200 lichen samples were collected and are in the process of being formally identified.

POLAR KNOWLEDGE Aqhaliat

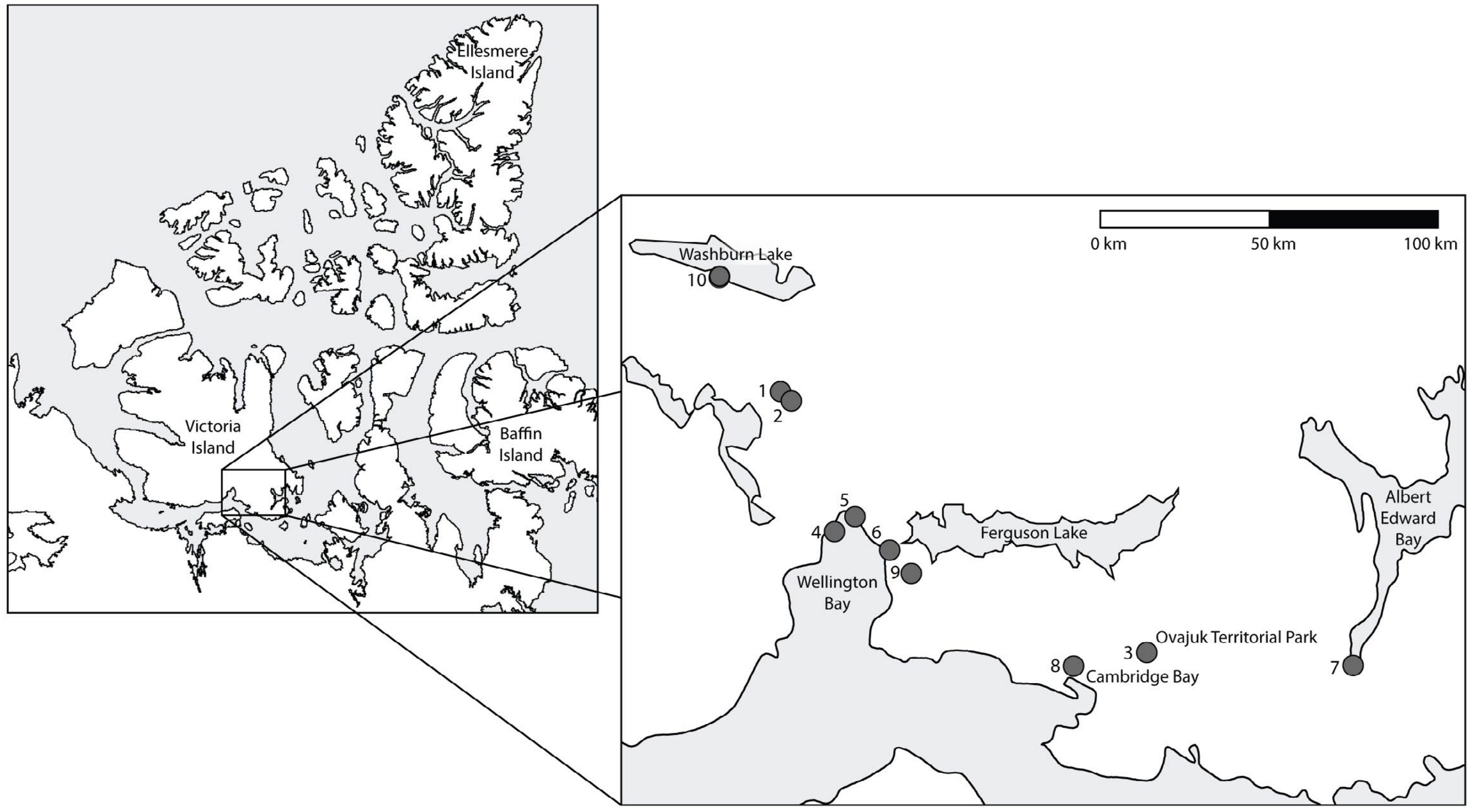


Figure 1: Study area and sampling sites visited in the vicinity of Cambridge Bay. Site numbers correspond to Table 1.

Preliminary observations of lichen communities near CHARS

Lichens were the dominant vegetation type in most areas around Cambridge Bay, and especially so in the rock-dominated landscapes. They also contributed to biological soil crusts, which occur in areas where soil formation has started. Algal and lichen communities were also located under transparent rocks (quartz) in a greenhouse-like environment (termed *hypoliths*). Our preliminary investigations suggest three main types of vegetation communities: (1) Vascular plants intermixed with lichens dominated by fruticose Arctic-alpine species (*Gowardia nigricans, Bryoria nitidula, Cetraria islandica, Cetraria aculeata, Flavocetraria nivalis, Thamnolia vermicularis, Vulpicida tilesii, Evernia perfragilis*), with a few mosses restricted to the most humid sites (Fig. 2a, 2b).

In this community type, lichen biomass is substantial, and is likely in a dynamic, competitive balance with vascular plants and sensitive to any environmental (e.g., climate) changes; (2) Lichen vegetation densely covering rocks and boulders, and also including extensive areas of small stones (often around 100–200 mm across and around 20–30 mm thick) and small pebbles (Fig. 3a, 3b). Bipolar species such as *Rhizocarpon geographicum, Rhizoplaca melanophthalma, Sporastatia testudinea, and Umbilicaria decussata* were frequently found in high abundance. In many cases, this vegetation was similar to that occurring in some areas of the southern polar Transantarctic Mountains (Green et al. 2011), offering an interesting opportunity for bipolar ecological and taxonomical comparisons; and (3) Biocrust, made up of crustose lichens (*Cladonia* sp., *Fulgensia bracteata, Ochrolechia sp., Ochrolechia frigida, Pertusaria af. dactylina, Pertusaria* af. *panyrga, Psora decipiens*), mosses and probably cyanobacteria (Fig. 4a, 4b).

This biocrust shows similarities with those from all around the world, both in polar and arid regions. Biocrust communities are not common in more humid Arctic regions such as the Svalbard Archipelago, Iceland, and Northern Scandinavia. The extensive presence of biocrusts in some areas of the southern shore of Victoria Island opens interesting research opportunities to integrate the Arctic into the international effort to understand these unique systems.

Table 1: Sampling sites visited during the study, including site names and GPS coordinates.

Site No.	Date	Site Name	Latitude	Longitude
1	7/21/2018	Southern Victoria Island Site 1	69.77871	-107.04295
2	7/21/2018	Southern Victoria Island Site 2	69.75728	-106.96758
3	7/21/2018	Ovajuk (Mt Pelly)	69.16298	-104.57033
4	7/23/2018	Wellington Bay Site 1	69.45022	-106.65907
5	7/23/2018	Wellington Bay Site 2	69.4864	-106.52231
6	23/7/18 & 27/7/18	Wellington Bay Site 3 Ekaluktok (Ferguson Lake outflow)	69.40802	-106.28632
7	7/24/2018	Albert Edward Bay	69.11751	-103.20293
8	7/25/2018	Ekaluktutiak (Cambridge Bay)	69.13356	-105.05821
9	7/27/2018	Ovayoalok (Ridge south of Ferguson Lake)	69.35333	-106.13998
10	7/28/2018	Washburn Lake	70.04475	-107.48449

Proposed research themes

A) Biodiversity, identifying the lichens:

The role of lichens in High Arctic food webs cannot be determined unless the species present can be accurately and easily identified. The first accurate identifications require suitable experts. However, a system should be developed that is also user-friendly to non-experts. We recommend the following actions: (1) encourage field surveys with targeted collection of lichens; (2) capture local information from elders regarding species presence, especially with regard to snow occurrence and persistence; (3) support visits by recognized experts to undertake further collecting and also to make identifications at CHARS as well as produce simple guides to the more obvious lichens; (4) initiate DNA barcoding of identified samples so that accurate determinations by non-experts are possible; and (5) develop a properly curated herbarium for all samples, including a DNA reference collection, at CHARS.

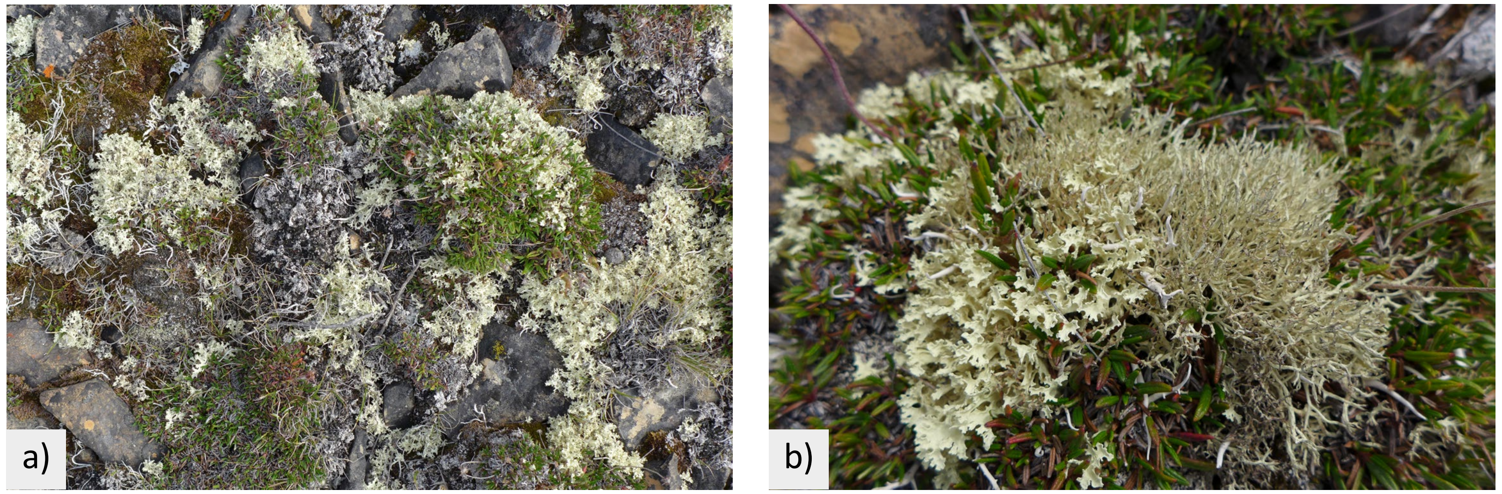


Figure 2: (a) Mixed vascular plant and lichen community; the most common lichens are of the fruticose form (like little trees), which can reach the light and compete with the leaves of the higher vascular plants and (b) The fruticose lichens Flavocetraria nivalis (L.) Kärnefelt and Thell (left side) and Evernia perfragilis Llano (right side) and between both, Thamnolia vermicularis (Sw.) Ach. ex Schaerer, which are all commonly found among the vascular plants.

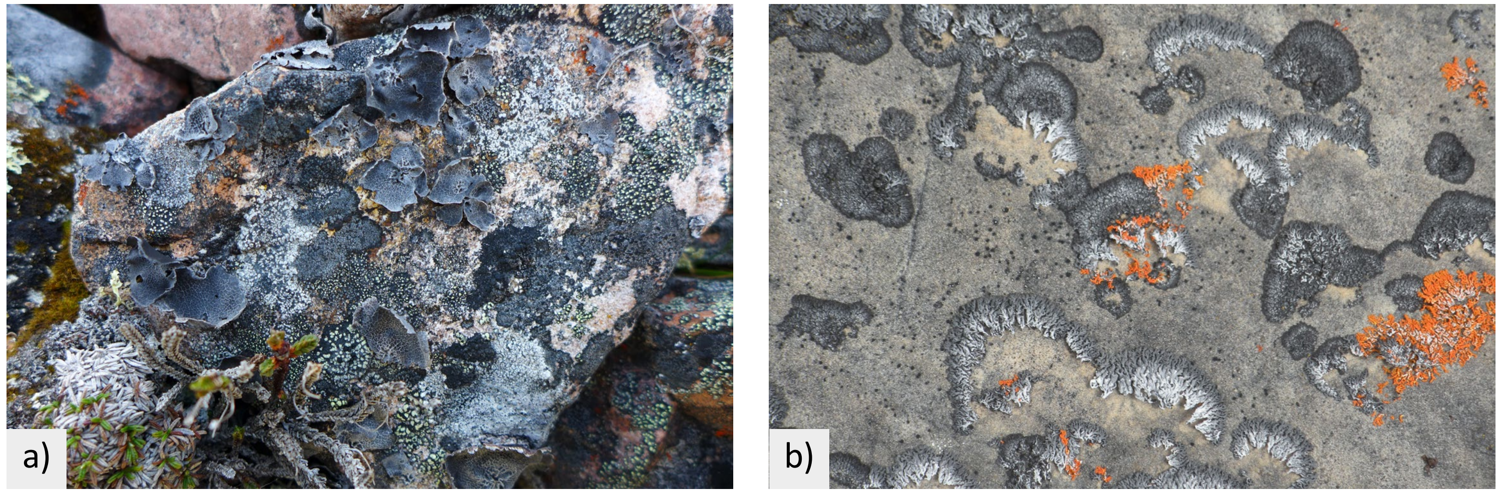


Figure 3: (a) An epilithic lichen community (Physcia spec., Rusavskia elegans), which provides excellent possibilities for growth studies and (b) Rich lichen community dominated by leaf-like Umbilicaria species and various crustose thalli, including the lichen most studied for growth rates, Rhizocarpon geographicum.

B) Ecology of lichens:

Lichens are a major component of the local vegetation communities. However, no readily accessible or published information exists at present. One consequence is that the spectacular lichen communities around Cambridge Bay do not get the research attention required. At present, research tends to occur in Alaska and Svalbard, likely due to the ready access to sites and facilities. The recent establishment of the CHARS campus offers enhanced access to nearby field sites as well as excellent on-site laboratory facilities. In order to make further progress, community descriptions are needed with rapid, targeted publication. Vegetation research (mostly vascular plant) has been carried out over recent years through satellite mapping and ground-truthing measurements (e.g., McLennan et al. 2018). This provides an excellent opportunity to progress lichen ecology and is needed to monitor responses to changes in climate (see subsection D below). However, detailed descriptions of dedicated research sites (e.g., within the CHARS Experimental and Reference Area) are needed to provide clear information

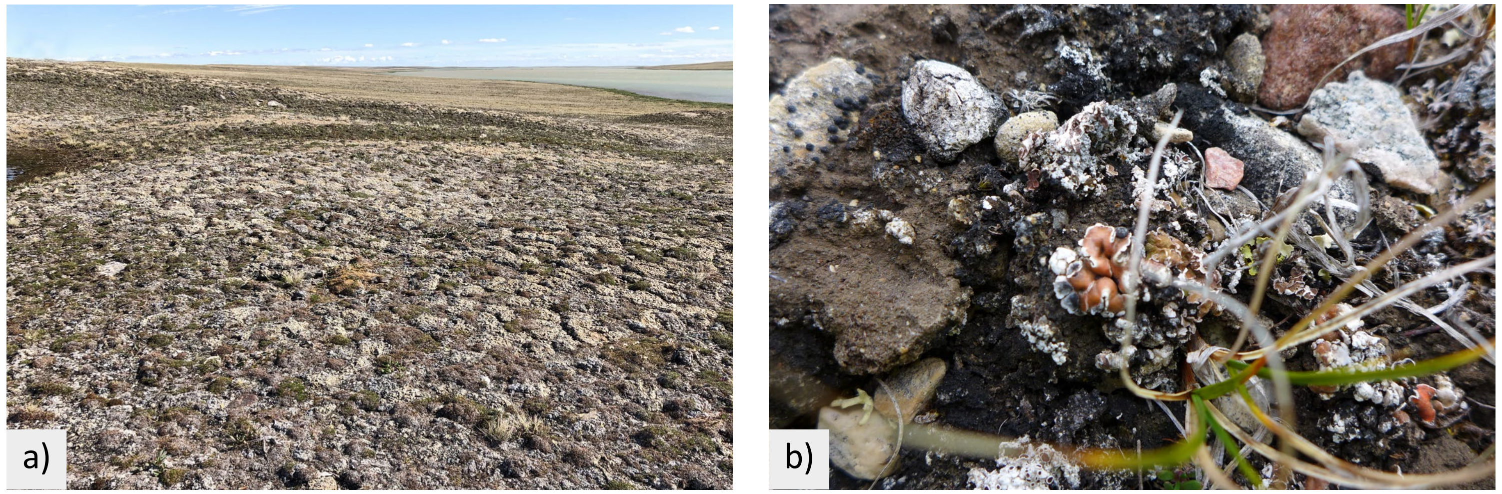


Figure 4: (a) Soil-crust lichens growing over a humid surface first created by the higher plants. Again, fruticose (tree-like) lichens are easier to see, but other crustose lichens actually grow on the soil surface and (b) Soil-crust lichen species Psora decipiens), which is cosmopolitan, including desert areas in Spain and the United States. Such lichens have recently been found to show complex adaptations to local climate.

on both vascular and non-vascular (lichens, mosses) plants, in conjunction with the existing vegetation classification program, to reveal special features of the region. This work must appear in the primary scientific literature to be of use to international researchers.

C) Landscape-level descriptions:

Vascular plant and lichen communities are determined by soil moisture in summer and snow cover in winter, with limited snow cover or winter exposure causing more arid conditions where lichens can dominate (CHARS 2015). Long-lying snow deters lichens whilst occasional cover with melt will favour them. Information on snow cover and duration will certainly exist within the local community and efforts should be made to obtain this valuable local knowledge.

D) Ecophysiology — understanding how lichens work:

There is currently no information on the ecophysiology of lichens and vascular plants in the vicinity of Cambridge Bay. Even in the research assessment by CHARS (CHARS 2015), the estimates for phytomass and net annual production come from a paper with information from Siberia. Most northern hemisphere research on tundra systems has been based in Alaska and, more recently, Svalbard. The latter has a climate that is very different to that of Cambridge Bay and the Nunavut region. The development of suitable systems to measure photosynthesis in both the laboratory and field is essential. Suitable growth chambers already exist in the laboratories at CHARS such that "over winter" studies are also possible. The satellite-based remote sensing and mapping of vegetation will also benefit, if actual productivity and related parameters such as chlorophyll content, biomass, and major nutrients can be determined and linked to the standard spectral coefficients. Suggested research themes are as follows:

1) *Photosynthetic performance of key species, lichens and vascular plants*. Portable equipment can be used to allow measurements in the field and in the laboratory at CHARS.

2) *Annual activity patterns of lichens*. Lichens and bryophytes are only active when hydrated (poikilohydric). Antarctic and alpine research has shown that activity patterns can vary considerably from that expected based on the general climate. Accordingly, actual activity patterns are best determined using "non-contact" chlorophyll fluorescence systems. Such systems have been extensively trialed in Antarctica and alpine sites. Because key environmental factors (light, temperature, relative humidity) are also recorded, the assembled database can reveal the main factors controlling performance as well as provide key data to develop models for predicting community change.

3) *Global comparisons*. Some lichen species have been investigated across large latitudinal gradients (e.g., *Cetraria aculeata* from the Antarctic to Europe), and evidence of adaptation has often been found. The main aim is to establish CHARS as a suitable site for global comparisons that are relevant to overarching themes such as climate change.

4) *Monitoring change*. The greening of the Arctic is an established process (Fauchald et al. 2017), and CHARS has decided that monitoring will be a key function of the new research station. Lichens are effective organisms to track climate-related changes, and the best method is the establishment of monitoring sites. Lichenometry is the study of lichen growth rates, and sites need to be established where lichen thalli are photographed each year and their growth rates determined. Once the growth rates have been established, they can then be used to assist other research areas such as dating exposed surfaces, providing insights on surface stability and corroborating archaeological data. Some sites show almost complete lichen cover. However, it is not known how long it takes to achieve this coverage. Rates of recovery can be established by experimentally disturbing sites and then monitoring the recovery. The monitoring of long-term change is best carried out by establishing sites that have been accurately mapped, or at least photographed, and then repeating the mapping at set intervals. In the case of lichens, such sites are small, approximately one metre square, and can be easily set up at multiple locations. Seasonal acclimation measurements of CO_2 exchange through the summer period will reveal whether the plants respond to the rapidly changing conditions.

5) *Soil metagenomics*. Plants and lichens interact with and change the soil microbiota, and such changes can be rapid. Metagenomics (or environmental genomics) can be defined as "the application of modern genomics technique without the need for isolation and laboratory cultivation of individual species." Metagenomics can provide valuable insights into the functional ecology of environmental communities such as in soils. DNA sequencing can also be used more broadly to identify species present in a body of water, debris filtered from the air, or samples of soil. This can establish the range of invasive species as well as endangered species, and track seasonal populations. We aim to obtain information on soil diversity and on changes in that biodiversity through the seasons at Cambridge Bay. This will be achieved by regular soil sampling, starting in April 2019, with molecular analysis in late 2019 and early 2020. The actual sample preparation and interpretation can be done at CHARS with the DNA sequencing undertaken at a suitable Canadian facility.

Community considerations

Country foods such as Arctic hare, caribou, and muskox are known to eat lichens. Lichens are very common around Ikaluktutiak (Cambridge Bay), even the dominant vegetation in some places. However, very little is known about their diversity and abundance, as they can be difficult to identify. An assessment by international researchers visiting the CHARS campus in July/August 2018 provided several suggestions. In particular, emphasis should be given to getting as many lichens identified and named as possible. Local lichen communities need to be described with input from local people (e.g., elders), as this will provide an important historical context regarding the possible presence or absence of different species. Simple identification systems such as guide books and DNA barcoding methods will then allow non-specialists to identify species more easily and allow for community-based monitoring. The DNA-based methods will also allow assessment of which species are important in the diets of country foods. The abundance of lichens and their annual contribution to the ecosystem productivity needs to be determined, as this is relevant to predicting effects of climate change. As vegetation shifts with changing climate, certain vegetation types might outcompete lichens and replace them in the local area. Overall, CHARS is in an excellent location to undertake lichen research.

Conclusions

CHARS is well situated to become a centre of research on High Arctic terrestrial biology and contribute to a better understanding of the stability and resilience of the local landscape. Emphasis should be given to identifying as many lichen species as possible and setting up systems (e.g., DNA barcoding) that will allow non-specialists to identify them more easily. Monitoring programs that allow growth rates to be determined could be used to establish the ages of rock surfaces or detect changes in climate. Local lichen communities need to be described with input from local people (e.g., elders) to assess how communities may have changed over time and how snow cover might influence the occurrence of lichen communities. The actual biomass of lichens present and their annual contribution to ecosystem productivity also need to be determined, as this is relevant to predicting effects of climate change.

Acknowledgements

We are grateful to George Angohiatok, Erin Cox, and Simona Wagner for assistance in the field and/or laboratory; to Donald McLennan, Johann Wagner, Sergei Pomanorenko, and Samantha McBeth for their input and advice; and to Monica Young for producing Figure 1. We also thank helicopter pilot Fred Jones for safely transporting us to the remote field sites.

References

Canadian High Arctic Research Station. 2015. Towards the development of the Canadian High Arctic Research Station (CHARS) as a centre for science and technology in Canada and the circumpolar north: Regional social and ecological context, baseline studies, and monitoring pilots. Available from https://above.nasa.gov/Documents/CHARS_Science_Summary_June_2015_DRAFT.pdf.

Edwards, R.Y., Soos, J., and Ritcey, R.W. 1960. Quantitative observations on epidendric lichens used as food by caribou. *Ecology* 41:425–431.

Fauchald, P., Park, T., Tømmervik, H., Myneni, R., and Hausner, V.H. 2017. Arctic greening from warming promotes declines in caribou populations. *Science Advances* 3:e1601365.

Green, T.G.A., Sancho, L.G., Tuerk, R., Seppelt, R.D., and Hogg, I.D. 2011. High diversity of lichens at 84º S suggests preglacial survival of species in the Ross Sea Region, Antarctica. *Polar Biology* 34:1211–1220.

McLennan, D.S., MacKenzie, W.H., Meidinger, D., Wagner, J., and Arko, C. 2018. A standardized ecosystem classification for the coordination and design of long-term terrestrial ecosystem monitoring in Arctic-Subarctic biomes. *Arctic* 71(Suppl. 1):1–15. Available from https://doi.org/10.14430/arctic4621.

Meidinger, D., MacKenzie, W., and Wagner, J. 2015. Vegetation and ecosystems. Anon 2015. (pp. 29-46).

Persson, H. and Holmen, K. 1961. Bryophytes collected during the Arctic field trip of the 9th International Botanical Congress. The Bryologist 64:179–198.

Thomas, P.A., Sheard, J.W., and Swanson, S. 1994. Transfer of 210Po and 210Pb through the lichen-caribou-wolf food chain of northern Canada. Health Physics 66:666–677.

Thomson, J.W. and Weber, W. A. 1992. Lichens collected on the Arctic excursion of the 9th International Botanical Congress. The Bryologist 95:392–405.

POLAR KNOWLEDGE Aqhaliat

VASCULAR SYNPHENOLOGY OF PLANT COMMUNITIES AROUND CAMBRIDGE BAY, VICTORIA ISLAND, NUNAVUT, DURING THE GROWING SEASON OF 2015

Johann Wagner[1,*], Donald S. McLennan[1], and A.K. Pedersen[1]

[1] *Polar Knowledge Canada, Cambridge Bay, Nunavut, Canada*

* johann.wagner@polar.gc.ca

Abstract

Phenology is the study of the timing of life cycle events, and the phenological development of plant species is strongly dependent on seasonal variations in environmental factors, especially temperature. Phenological records of entire plant communities—synphenology—over periods of many years can serve as invaluable proxies for interannual changes in temperature that are due to climate change and global warming. While the synphenology of temperate ecosystems has been fairly well researched, there are comparatively fewer phenological observations in the Arctic, and synphenological work has never been performed in the high-latitude regions around Cambridge Bay, Victoria Island, Nunavut. The phenology of the most representative vascular plant species in the region was recorded during the growing season of 2015, from mid-June to the beginning of September. Vegetative (leaf) as well as generative (flower/seed) development in shrubby, herbaceous, and graminoid plant species was assessed at weekly intervals using a phenological key with 11 phenological stages, from the development of the first leaf / first floral bud to leaf death/seed dispersal. In addition, the different phenological stages of plants were documented by digital photographs that were taken at the time of phenological assessment. This phenological data has been assembled into synphenological diagrams, which facilitate the overview of the phenological development of entire plant communities as well as the comparison of different years.

Introduction

Phenology can be defined as the study of life cycle phases (phenophases) of plants and animals in their temporal occurrence throughout the year, whereas phytophenology is the branch of phenology studying the seasonal rhythms of plants (Puppi 2007; Forrest and Miller-Rushing 2010). The phenology of plants is strongly dependent on environmental factors in harsh and highly seasonal environments such as tundra ecosystems (Thórhallsdóttir 1998), with temperatures having the most important influence (Mooney and Billings 1961; Thórhallsdóttir 1998; Bjorkman et al. 2015), as well as photoperiod (Mooney and Billings 1961; Heide 1992; Keller and Körner 2003) and snow cover (Borner et al. 2008; Bjorkman et al. 2015) having significant roles. Plant species in all environments are shifting their phenology in response to global climate change (Cleland et al. 2007). Arctic regions are already experiencing the fastest

Suggested citation:

Wagner, J., McLennan, D.S., and Pedersen, A.K. 2018. Vascular synphenology of plant communities around Cambridge Bay, Victoria Island, Nunavut, during the growing season of 2015. Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 9–19. DOI: 10.35298/pkc.2018.02*

changing climate, with increasing temperatures and changes in precipitation (IPCC 2007), which are expected to strongly influence the life cycle events of plants that are growing under significant environmental constraints. Phytophenological observation over long periods of time can serve as invaluable proxies for climate variation and change (Fang and Chen 2015).

Given the importance of monitoring the phenology of plants in polar and alpine regions, a number of studies investigate the timing of life cycle phases of plants in natural or simulated tundra environments (Borner et al. 2008; Molau 1993; Mooney and Billings 1961; Thórhallsdóttir 1998; Wagner and Simons 2008; Wookey et al. 1993; Bjorkman et al. 2015; Wheeler et al. 2015). However, most methods focus on an individual species or a limited number of species (Bean and Henry 2003; Molau et al. 1996; Mark et al. 2016; Panchen and Gorelick 2015; Reynolds 1984), either using historical phenological sources (Panchen and Gorelick 2017) or studying species taken out of their plant community context (Panchen and Gorelick 2016). Synphenological approaches, which investigate the phenological rhythms of entire plant communities (Dierschke 1989b; Puppi 2007), have been employed predominantly in temperate, mostly forest ecosystems (Coldea and Wagner 1993–1994; Dierschke 1972, 1982, 1989a, 1991; Pilková 2015; Wagner 1994). Few phenological studies investigating entire plant communities have been performed in high-latitude, tundra environments.

This paper presents the results of a preliminary synphenological study in several of the Arctic ecosystems described around Cambridge Bay, Victoria Island, Nunavut (McLennan et al. 2018) during the growing season of 2015, from mid-June, shortly after snowmelt, to the beginning of September, after the senescence of most plant species.

Materials and methods

Synphenological observations were performed during the growing season of 2015, from mid-June to the beginning of September, at approximately weekly intervals at the sites presented in Table 1, in some of the more important ecosystems (ecosites) around Cambridge Bay (McLennan et al. 2018). For assessing the phenology, the method first introduced by Dierschke in 1972 and perfected in subsequent years (Dierschke 1982, 1989b, a, 1991) was used. The original phenological keys for vascular plants from Dierschke (1989b) were adapted to the characteristics of the flora of the Arctic, and are presented in Table 2. The phenological keys assess both the vegetative (leaf) and generative (flower/seed) development of the plants, and these keys were separated for shrubs, herbaceous plants, and graminoids. They characterize the phenological development of the plants through 11 stages, from early shoot / floral bud development to leaf senescence and death, as well as seed dispersal.

During the observations, an attempt was made to record the phenology of all vascular plants visible and identifiable on the sites. Additionally, the different phenological stages of plants were recorded by digital photographs that were taken at the time of phenological assessment, both for documenting the phenological stages and for a later confirmation of the phenological stages. The observations on the various phenological stages were assembled in a phenological table, with species ordered by their flowering phenology from earliest to latest. Table 3 presents an example of such a phenological table. Some of the plant species present in these ecosystems are small and inconspicuous, and were therefore identified for the first time only later in the season, or were not found again after an initial observation. Such species, for which insufficient phenological data was collected, were eliminated from the phenological tables. While such phenological tables already offer a useful insight into the phenological phases of most of the plant species of the ecosites, in the case of a larger number of species, a graphical representation of the data from these phenological tables in the form of synphenological diagrams makes the overview and analysis of the phenological data easier. Similar to phenological tables, in which dates are in columns, in synphenological diagrams, the date is on the horizontal axis, while species are presented on the vertical axis in order of their flowering phenology, from earliest to latest. Their vegetative development is depicted by horizontal bars with vertical lines, higher line densities corresponding to vegetative phenology stages closer to full leaf development. Their generative development is represented by vertical bars, the height of which suggest the magnitude of flowering, with colours corresponding to the flower colour. Figures 1 and 2 preliminarily present the synphenological diagrams of two of the investigated sites from Table 1.

Table 1: Sites on which synphenological observations were performed during the growing season of 2015.

Site Name	Mount Pelly Road	Wetland	Seashore	Long Point	Dew Line Road	West Road
Latitude	69.15672	69.15849	69.10578	69.09373	69.15757	69.11432
Longitude	-104.91185	-104.91240	-105.38382	-105.44079	-105.19082	-105.37647
Ecosite	01 – *Dryas integrifolia – Saxifraga oppositifolia* (lithic)	09 – *Carex aquatilis*	16 – *Leymus mollis* (marine littoral)	16 – *Leymus mollis* (marine littoral)	01 – *Dryas integrifolia – Saxifraga oppositifolia*	01 – *Dryas integrifolia – Saxifraga oppositifolia* with *Vaccinium uliginosum*
Description	Mesic tundra, zonal ecosite most reflective of regional bioclimate	Sedge fen, the most common wetland type	Seashore ecosite on sandy substrate	Seashore ecosite on sandy substrate	Mesic tundra, zonal ecosite most reflective of regional bioclimate	Mesic tundra, zonal ecosite most reflective of regional bioclimate

Table 2: The phenological stages recorded for vascular plants at the site.

Shrubs

Vegetative phenological stage	Generative phenological stage
0 — buds completely closed	0 — no floral buds
1 — buds with green tips	1 — 1st buds/inflorescence visible
2 — 1–30% leaf development	2 — buds just before opening
3 — 31–60% leaf development	3 — 1–30% of flowers open
4 — 61–99% leaf development	4 — 31–60% of flowers open
5 — maximum leaf development	5 — full flowering
6 — first leaf senescence	6 — most or all flowers wilted
7 — 1–30% of leaves turned colour	7 — fruits visible
8 — 31–60% of leaves turned colour	8 — fruits almost at full size and green
9 — 61–99% of leaves turned colour	9 — fruits almost ripe, brown or dry
10 — shrub leafless or with dead leaves	10 — seeds dispersing

Herbaceous

Vegetative phenological stage	Generative phenological stage
0 — fully snow-free; only dead leaves	0 — no buds/inflorescence
1 — first growth of the season/first leaf	1 — 1st buds/inflorescence visible
2 — 1–30% leaf development	2 — buds just before opening
3 — 31–60% leaf development	3 — 1–30% of flowers open
4 — 61–99% leaf development	4 — 31–60% of flowers open
5 — maximum leaf development	5 — full flowering
6 — first leaf senescence	6 — most or all flowers wilted
7 — 1–30% of leaves dry	7 — petals fully shed, and fruits visible
8 — 31–60% of leaves dry	8 — fruits almost at full size and green
9 — 61–99% of leaves dry	9 — fruits almost ripe, brown or dry
10 — stem and leaves completely brown and dead	10 — fruits fully ripe and seeds dispersing (bulbils dispersing)

Graminoids

Vegetative phenological stage	Generative phenological stage
0 — fully snow-free; only dead leaves	0 — no inflorescence
1 — first shoot of the season/first leaf	1 — 1st inflorescence visible
2 — 1–30% of shoots developed	2 — inflorescences just before opening
3 — 31–60% shoots developed	3 — first anthers visible
4 — 61–99% shoots developed	4 — 31–60% of anthers open
5 — maximum shoot development	5 — full flowering
6 — first leaf senescence	6 — anthers beginning to senesce
7 — 1–30% of leaves dry	7 — anthers fully senescent, achenes visible
8 — 31–60% of leaves dry	8 — fruits almost at full size and green
9 — 61–99% of leaves dry	9 — fruits almost ripe, brown or dry
10 — stem and leaves completely brown and dead	10 — fruits fully ripe and dispersing

p — overwintered, persistent leaves from previous year
m — marcescent

Results and discussion

In contrast to temperate ecosystems, in which the phenological development of plant communities stretches over five to six months of growing season, with up to 10 clearly marked phenophases (Coldea and Wagner 1993–1994; Dierschke 1982, 1989a, 1991; Wagner 1994), the phenological development of plants in our study sites is strongly compressed, with little discernible separation into phenophases (Fig. 1, 2).

The strong compression of phenophases can be attributed to having only six to eight weeks available for plant growth in the Arctic climate of Cambridge Bay, where the cool and short growing season puts severe constraints on plant development. Depending on the particular year, complete snowmelt does not usually occur before mid-June (Environment Canada, 1953 onwards), with most plants already senescing in the second half of August (Fig. 1, 2). Therefore, there are only three somewhat discernible phenophases. The earliest phenophase, in which only species that overwinter with almost mature floral buds bloom, occurs immediately after snowmelt, while there is still only minimal leaf development in these species; for example, the purple saxifrage (*Saxifraga oppositifolia*), the willows *Saxifraga richardsonii* and *S. arctica*, and a few *Draba*. The second phenophase starts with the flowering of *Pedicularis*

Table 3: Phenological table of a marine littoral ecosystem at Long Point, Cambridge Bay.

Date		20-6-15	27-6-15	5-7-15	10-7-15	21-7-15	31-7-15	8-8-15	19-8-15	27-8-15	3-9-15
Saxifraga oppositifolia	V	3	4	5	5	5	5	5	6	7	7
	G	4	5	6	6	7	8	8	9	10	10
Salix arctica	V	1	3	4	5	5	5	5	6	10	9
	G	3	5	5	6	7	8	8	10	10	10
Draba corymbosa	V	2	4	4	5	5	5	5	7	7	7
	G	2	5	5	6	6	8	8	10	10	10
Draba glabella	V	2	3	3	3	5	5	5	7	7	7
	G	2	4	5	5	7	8	8	10	10	10
Pedicularis lanata	V	1	3	5	5	5	5	5	6	6	10
	G	0	1	5	5	7	8	8	9	9	10
Saxifraga tricuspidata	V	2	3	4	5	5	5	5	6	6	8
	G	2	2	3	5	5	6	8	9	10	10
Oxyria digyna	V	2	3	4	5	5	5	5	7	8	9
	G	2	3	5	6	7	8	10	10	10	10
Oxytropis arctica	V	2	3	4	5	5	5	5	6	7	8
	G	1	3	5	5	5	8	9	9	9	10
Papaver radicatum	V	2	3	4	4	5	5	5	6	6	7
	G	1	1	4	5	6	8	8	10	10	10
Silene acaulis	V	2	4	4	5	5	5	5	5	6	7
	G	0	1	4	5	6	7	7	9	10	10
Taraxacum phymatocarpum	V	2	3	4	4	5	5	5	6	6	9
	G	1	1	4	5	5	10	10	10	10	10
Oxytropis arctobia	V	1	2	3	5	5	5	5	7	7	7
	G	0	3	1	5	6	8	9	9	10	10
Armeria scabra	V	2	3	4	5	5	5	5	6	6	7
	G	1	2	2	5	6	6	7	8	10	10
Silene uralensis	V	1	2	4	4	5	5	5	7	7	10
	G	0	1	3	5	5	8	10	10	10	10
Potentilla pulchella	V	1	4	4	5	5	5	5	5	6	7
	G	0	3	3	5	5	6	7	9	10	10

Date		20-6-15	27-6-15	5-7-15	10-7-15	21-7-15	31-7-15	8-8-15	19-8-15	27-8-15	3-9-15
Minuartia rossii	V	1	3	3	5	5	5	5	5	6	8
	G	0	3	3	5	5	5	7	7	7	9
Astragalus alpinus	V	1	3	4	4	5	5	5	6	6	8
	G	0	1	3	4	5	6	7	9	9	10
Chamerion latifolium	V	1	2	3	4	5	5	5	5	6	9
	G	0	1	2	2	5	5	7	9	9	9
Poa arctica	V	1	2	2	2	5	5	5	5	6	7
	G	0	0	1	2	5	6	7	7	9	10
Festuca brachyphylla	V	0	1	2	4	5	5	5	6	6	7
	G	0	0	1	2	4	6	7	9	9	10
Leymus mollis ssp. villosissimus	V	1	2	2	3	4	4	5	5	6	7
	G	0	0	2	1	3	6	6	6	8	8

lanata, followed by the blooming of most other plants in the ecosystem. The last phenophase starts at the end of July or beginning of August with the flowering of a few late bloomers such as *Hedysarum boreale* ssp. *mackenzii*, *Leymus mollis* ssp. *villosissimus* and *Arctagrostis latifolia* (Fig. 1, 2). When considering the flowering of the various species, there does not seem to be any tendency for flowers of a certain colour to bloom together in a certain phenophase, which is the case in some temperate ecosystems, where species with yellow flowers tend to bloom towards the end of the growing season (Coldea and Wagner 1993–1994; Wagner 1994).

The senescence of most plants appears to be starting mid-August, when daily mean temperatures go below +7°C for the first time (Environment Canada, 1953 onwards). After this date, the daily mean temperatures decrease rapidly, and by the end of August most plants are completely senescent (Fig. 1, 2).

An interesting flowering phenology is exhibited by the legume *Oxytropis arctobia*, which flowers profusely in the first half of July, together with the species *Dryas integrifolia* and *Oxytropis arctica*. This species presents, however, a secondary flowering peak of a smaller magnitude very late in the season, towards the end of August, after its leaves start senescing (Figure 1). It is unknown whether this secondary blooming phase is due to a small number of individuals that delayed their flowering by several weeks, or individuals that are flowering twice, once during the main flowering phase and a second time late in the season. Because of the flowering energy investment constraints that plants in the Arctic are subjected to, it is almost certain that the secondary flowering event is due to delayed flowering of a subset of individuals. The evolutionary and adaptive significance of this second blooming event is presently unknown, but would represent an interesting topic for a future project.

Conclusions and community consideration

Because of the sensitivity of plant phenology to environmental factors (i.e., weather and climate variations), long-term phenological and synphenological observations are an important tool, not only for ecosystem monitoring, but also for climate change monitoring. Moreover, phenological observations require few resources, and are therefore particularly well suited for community-based monitoring, by which local communities, very observant to the slightest environmental changes, can bring an invaluable

Figure 1: Synphenological diagram for a 16 – Leymus mollis *marine littoral ecosystem at Long Point, Cambridge Bay.*

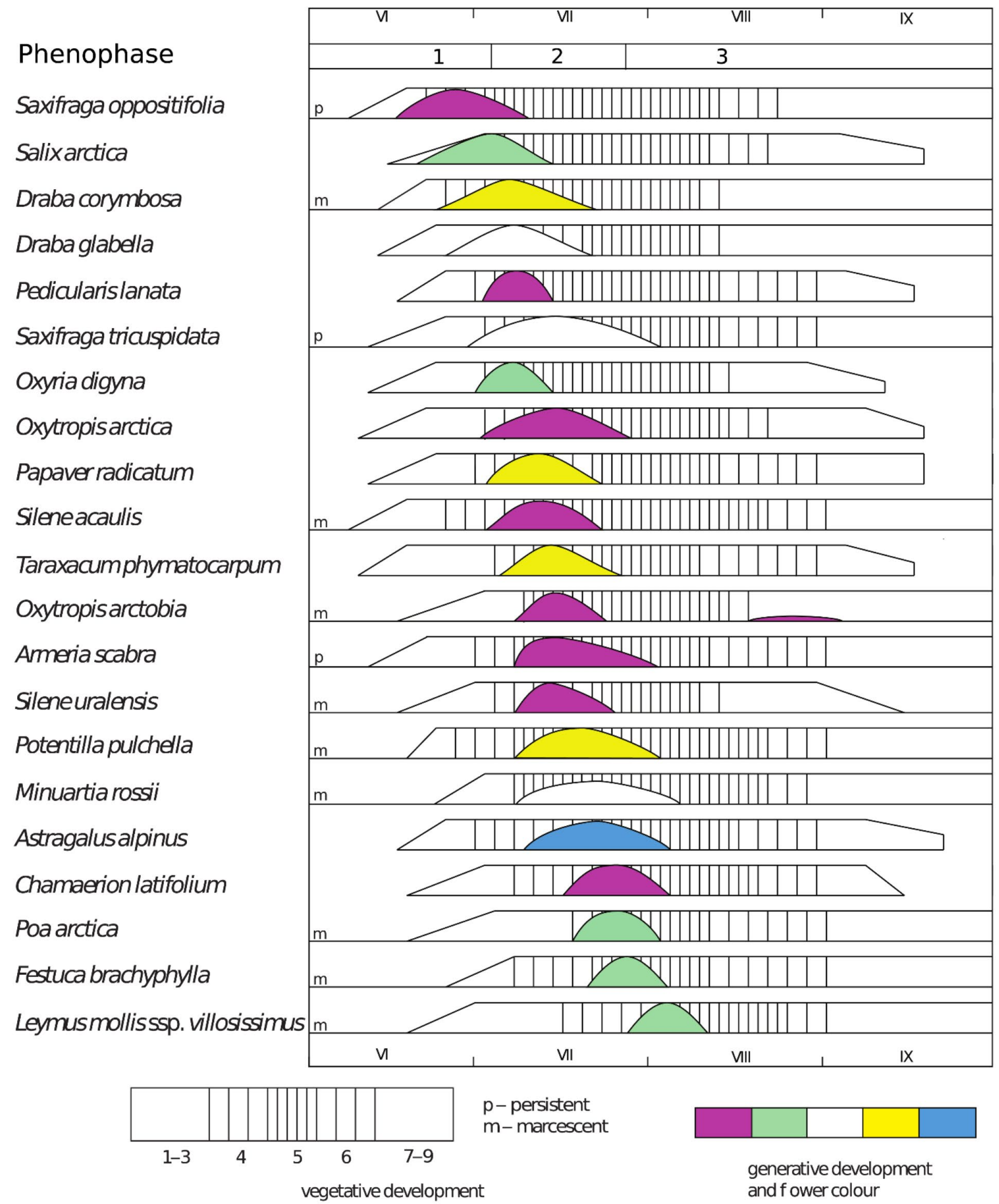
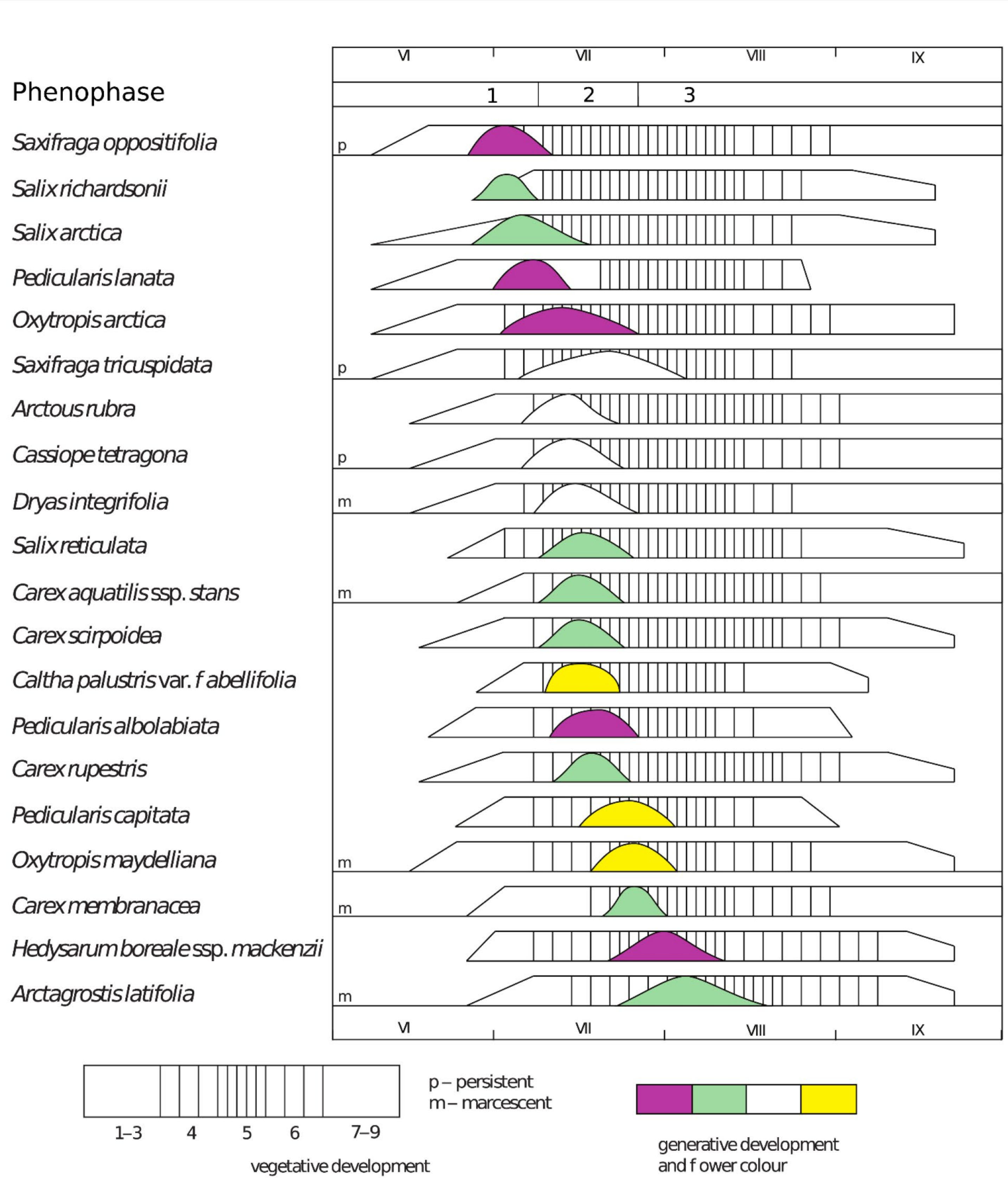


Figure 2: Synphenological diagram for a 01 – Dryas integrifolia *–* Saxifraga oppositifolia *mesic tundra ecosystem along the Dew Line Road, Cambridge Bay.*



contribution. Our synphenological observations performed over the duration of a single growing season are but a glimpse into the complex interactions between ecosystems and a harsh, unpredictable environment, both within the growing season and between growing seasons. A phenological monitoring program continued over many years, or even decades, would bring a much more accurate picture of the interplay between plants, ecosystems, and the changing environment. Synphenological diagrams offer a comprehensive overview of the phenology of entire plant communities. When relative cover of plants in various phenological stages is recorded during observations, synphenological diagrams can offer both qualitative information about the phenophases and quantitative data on the magnitude of these phenological phases. As next steps, we will continue our synphenological observations in the most important ecosystems of southeastern Victoria Island, using an improved phenological key system with 12 phenological stages and also recording the relative cover of species in the various phenological stages.

Acknowledgements

We would like to thank Cathy Anablak and Leonard Wingnek for their help with the phenological observations in field. We would also like to thank the Nunavut Department of Environment for issuing the Wildlife Research Permit for this project.

References

Bean, D. and Henry, G. 2003. CANTTEX field manual: Part A—setting up a basic monitoring site. Eman North, London.

Bjorkman, A.D., Elmendorf, S.C., Beamish, A.L., Vellend, M., and Henry, G.H.R. 2015. Contrasting effects of warming and increased snowfall on Arctic tundra plant phenology over the past two decades. *Global Change Biology* 21 (12):4651–4661. doi:10.1111/gcb.13051.

Borner, A.P., Kielland, K., and Walker, M.D. 2008. Effects of simulated climate change on plant phenology and nitrogen mineralization in Alaskan Arctic tundra. *Arctic, Antarctic, and Alpine Research* 40 (1):27–38.

Cleland, E.E., Chuine, I. and Menzel, A. 2007. Shifting plant phenology in response to global change. *Trends in Ecology and Evolution* 22 (7):357–365.

Coldea, G. and Wagner, I. 1993–1994. Cercetări simfenologice asupra vegetației din bazinul superior al Văii Huzii (Muntele Săcel) (Synphenological research on the vegetation of the upper basin of the Huzii Valley, Săcel Mountain). *Contribuții Botanice:*23–28.

Dierschke, H. 1972. Zur Aufnahme und Darstellung phänologischer Erscheinungen in Pflanzengesellschaften (About recording and representation of phenological events in plant communities). In: Grundfragen und Methoden in der Pflanzensoziologie. Dr. W. Junk N.V., pp 291–311.

Dierschke, H. (1982) Pflanzensoziologische und ökologische Untersuchungen in Wäldern Süd-Niedersachsens: 1. Phänologischer Jahresrhythmus sommergrüner Laubwälder (Plant community and ecological investigations in the forests of southern Lower Saxony: I. Annual phenological rhythm of deciduous forests). Tuexenia 2:173–194.

Dierschke, H. 1989a. Kleinräumige Vegetationsstruktur und phänologischer Rhythmus eines Kalkbuchenwaldes (Small-scale vegetation structure and phenological rhythm of a beech forest on limestone). *Verhandlungen der Gesellschaft für Ökologie* 17:131–143.

Dierschke, H. 1989b. Symphänologische Aufnahme- und Bestimmungsschlüssel für Blütenpflanzen und ihre Gesellschaften in Mitteleuropa (Synphenological recording and identification keys for flowering plants and their communities in Central Europe). *Tuexenia* 9:477–484.

Dierschke, H. 1991. Phytophänologische Untersuchungen in Wäldern: Methodische Grundlagen und Anwendungsmöglichkeiten im passiven Biomonitoring (Plant phenology investigations in forests: Methodological basis and application possibilities in passive biomonitoring). *Beihefte zu den Veröffentlichungen für Naturschutz und Landshaftspflege in Baden-Württemberg* 64:76–86.

Environment Canada. Historical climate data for Cambridge Bay Airport, Nunavut (1953 onwards). Available from http://climate.weather.gc.ca/historical_data/search_historic_data_e.html [accessed 22 June 2018].

Fang, X. and Chen, F. 2015. Plant phenology and climate change. *Science China Earth Sciences* 58 (6):1043–1044. doi:10.1007/s11430-015-5077-7.

Forrest, J. and Miller-Rushing, A.J. 2010. Toward a synthetic understanding of the role of phenology in ecology and evolution. *Philosophical Transactions of the Royal Society B: Biological Sciences* 365 (1555): 3101 –3112.

Heide, O.M. 1992. Flowering strategies of the High-Arctic and high-alpine snow bed grass species *Phippsia algida*. *Physiol Plantarum* 85 (4):606–610.

Intergovernmental Panel on Climate Change. 2007. Climate change 2007: Synthesis report. Cambridge University Press, New York.

Keller, F. and Körner, C. 2003. The role of photoperiodism in alpine plant development. *Arctic, Antarctic, and Alpine Research* 35 (3):361–368.

Mark, A.K.G., Nanna, B., and Elisabeth, J.C. 2016. High Arctic flowering phenology and plant–pollinator interactions in response to delayed snow melt and simulated warming. *Environmental Research Letters* 11 (11):115006.

McLennan, D.S., MacKenzie, W.H., Meidinger, D.V., Wagner, J., and Arko, C. 2018. A standardized ecosystem classification for the coordination and design of long-term terrestrial ecosystem monitoring in Arctic-Subarctic biomes. Arctic 71 (Suppl. 1):1–15. Available from doi:https://doi.org/10.14430/arctic4621.

Molau, U. 1993. Relationships between flowering phenology and life history strategies in tundra plants. *Arctic, Antarctic, and Alpine Research* 25 (4):391–402.

Molau, U., and Mølgaard, P. 1996. ITEX manual. Danish Polar Center, Copenhagen.

Mooney, H.A. and Billings, W.D. 1961. Comparative physiological ecology of arctic and alpine populations of *Oxyria digyna*. *Ecological Monographs* 31 (1):1–29.

Panchen, Z.A. and Gorelick, R. 2015. Flowering and fruiting responses to climate change of two Arctic plant species, purple saxifrage (*Saxifraga oppositifolia*) and mountain avens (*Dryas integrifolia*). *Arctic Science* 1 (2):45–58. doi:10.1139/as-2015-0016.

Panchen, Z.A. and Gorelick, R. 2016. Canadian Arctic Archipelago conspecifics flower earlier in the High Arctic than the mid-Arctic. *International Journal of Plant Sciences* 177 (8):661–670. doi:10.1086/687984.

Panchen, Z.A. and Gorelick, R. 2017. Prediction of Arctic plant phenological sensitivity to climate change from historical records. *Ecology and Evolution* 7 (5):1325–1338. doi:10.1002/ece3.2702.

Pilková, I. 2015. Synphenology of herb layer of *Carpinion betuli* community in the Báb Forest. *Acta Universitatis Agriculturae Silviculturae Mendelianae Brunensis* 63 (5):1513–1521.

Puppi, G. 2007. Origin and development of phenology as a science. *Italian Journal of Agrometeorology* 3:24–29.

Reynolds, D.N. 1984. Alpine annual plants: phenology, germination, photosynthesis, and growth of three Rocky Mountain species. *Ecology* 65 (3):759–766.

Thórhallsdóttir, T.E. 1998. Flowering phenology in the central highland of Iceland and implications for climatic warming in the Arctic. *Oecologia* 114 (1):43–49.

Wagner, I. 1994. Observații fenologice asupra unei pajiști mezofile din bazinul superior al Văii Huzii (Muntele Săcel, Jud. Cluj) (Phenological observations on a mesophilous meadow in the upper basin of the Huzii Valley, Săcel Mountain, Cluj county). *Studia Universitatis Babeș-Bolyai, Biologia* XXXIX (1):15–18.

Wagner, I. and Simons, A.M. 2008. Divergence among Arctic and alpine populations of the annual *Koenigia islandica*: Morphology, life history, and phenology. Ecography 32 (1):114–122. doi:10.1111/j.1600-0587.2008.05497.x.

Wheeler, H.C., Høye, T.T., Schmidt, N.M., Svenning, J-C, and Forchhammer, M.C. 2015. Phenological mismatch with abiotic conditions—implications for flowering in Arctic plants. *Ecology* 96 (3):775–787. doi:10.1890/14-0338.1.

Wookey, P., Parsons, A.N., Welker, J.M., Potter, J.A., Callaghan, T.V., Lee, J.A., and Press, M.C. 1993. Comparative responses of phenology and reproductive development to simulated environmental change in Subarctic and High Arctic plants. *Oikos* 67:490–502.

THE DISTRIBUTION AND ABUNDANCE OF PARASITES IN HARVESTED WILDLIFE FROM THE CANADIAN NORTH:

A review

Virginia León-Règagnon[1,2*], Ian D. Hogg[3], and Paul D.N. Hebert[4]

[1] *Instituto de Biología, Universidad Nacional Autónoma de México, Mexico City, Mexico*

[2] *Centre for Biodiversity Genomics, University of Guelph, Guelph, Ontario, Canada*

[3] *Polar Knowledge Canada, Cambridge Bay, Nunavut, Canada*

[4] *Centre for Biodiversity Genomics, University of Guelph, Guelph, Ontario, Canada*

* *vleon@ib.unam.mx*

Abstract

Parasites are key components of Arctic ecosystems. The current rate of climate and landscape changes in the Arctic is expected to alter host-parasite interactions, creating a significant concern for the sustainability of Arctic vertebrates. In addition to direct effects on host populations, changes in parasite loads on wildlife can have significant impacts on the people who depend on these organisms for food. Parasites play important roles in maintaining ecosystem stability through the regulation of host populations, and can provide unique insights into ecosystem structure. The present review examines the literature on the parasites of harvested wildlife in the Canadian North, including studies in the Yukon, Northwest Territories, Nunavut, northern Quebec, and Newfoundland and Labrador. For host species with higher mobility, we included records from other regions, such as Greenland, Russia, and the Canadian Subarctic, when no parasitological studies were available for the Canadian North. In addition, we searched databases of the Parasite Collection at the Canadian Museum of Nature and the United States Parasite Collection for records from the Canadian North. We found records for 248 species of macroparasites in vertebrate species of country food of animal origin in the Canadian North, including flatworms, roundworms, thorny-headed worms, ticks, lice, fleas, flies, and tongue worms. This review highlights the need to extend the study of the parasites that infect the primary species of harvested wildlife in the Canadian North. More detailed information on parasite communities is particularly important as climate and landscape change raises the possibility that new parasite species will colonize the region. Building a DNA barcode library for the parasites from country food in the area will facilitate their identification and monitoring.

Introduction

Parasites are an important component of Arctic ecosystems, influencing the health and sustainability of wildlife populations and the people who depend on them (Hoberg et al. 2003; Davidson et al. 2011). Beginning in the 1940s, a succession of parasitologists and ecologists have explored parasitism in the Arctic, advancing understanding of the structure and function of host-parasite systems in this setting. In recent years, the recognition of rapid climate change in the North has stimulated increased effort (Kutz et al. 2012).

The current rate of climate and landscape change in the Arctic is expected to alter host-parasite interactions, creating a significant concern for the sustainability of Arctic vertebrates (Hoberg et al. 2008; Kutz et al. 2009; Polley et al. 2010). In addition to direct effects on host populations, changes in the parasite loads carried by wildlife can significantly impact the people who depend on these organisms for food. Parasites can affect the quality, quantity, and safety of meat or other animal products consumed by humans, and changes in parasite biodiversity and the associated disease processes can influence the levels and sustainability of host populations (Davidson et al. 2011).

Although often portrayed negatively, parasites play an important role in maintaining ecosystem stability through the regulation of host populations, and provide unique insights into the historical and current status of ecosystems. Parasites can, for example, provide information on the presence of direct or indirect interactions among species present in the ecosystem as well as information about the host habits (Hoberg 2010). Healthy ecosystems typically have a high diversity of parasites, reflecting the number of definitive (ultimate) and intermediate host species and vectors. As a result, the detection of a “normal” complement of parasites can be indicative of a healthy ecosystem. Conversely, the detection of “new” (invasive) parasites or very few parasite species can suggest otherwise (Hudson et al. 2006).

To use parasites as indicators of environmental health and to track or predict changes in parasitism and animal health, comprehensive data on parasite diversity, distributions, and life cycles are essential (Hoberg et al. 2003; Hoberg and Brooks 2008; Hoberg et al. 2008). Although considerable progress has been made in defining the diversity and ecology of parasites found in/on Arctic vertebrates (Rausch 1974; Hoberg et al. 2012a), there remain substantial knowledge gaps.

Methodology

The present review considers all available literature on the parasites of country food of animal origin in the Canadian North, defined as the land- and ocean-based territory of Canada that lies north of the southern limit of discontinuous permafrost, from northern British Columbia in the west to northern Labrador in the east (IPY, 2007–2008). We consulted three academic databases, Web of Science, JSTOR, and Google Scholar, with the search words parasite + arctic + Canada; further searches were conducted with the scientific and common names of the hosts + parasite. Studies out of the defined geographic range or without parasite identification to family or lower level were excluded. We also revised the cited literature of the publications found in the searches. For host species with high mobility, we included records from other regions, such as Alaska, Greenland, Iceland, Russia, and the Canadian Subarctic, when no parasitological studies have been conducted in the Canadian North. In addition, the databases of the Canadian Museum of Nature Parasite Collection and the United States Parasite Collection were searched for records of the host species in the Yukon, Northwest Territories, Nunavut, northern Quebec, and Newfoundland and Labrador; only records within the Canadian North were considered.

We considered vertebrate species regularly hunted for food in the Canadian North (Table 1). We also considered the wolf (*Canis lupus*) and wolverine (*Gulo gulo*), although rarely consumed, because they are reservoirs of parasites that transmit to humans and are frequently hunted for their fur. For parasite nomenclature, we followed the Encyclopedia of Life (http://eol.org) and specialized literature for each taxon.

Results

We found records for 248 species of macroparasites in vertebrate species of harvested wildlife in the Canadian North (Appendix 1, https://www.polardata.ca/pdcsearch/?doi_id=12962). Of these, 185 species were recorded within the Canadian North, and 63 were recorded outside this region; the 63 recorded outside this region were parasitizing species (mainly birds) that are also distributed in the Canadian North but have not been studied for parasites. The record includes platyhelminths (flatworms of the classes Monogenea, Digenea, and Cestoda); nematodes (roundworms);

Suggested citation:

León-Règagnon, V., Hogg, I. D., and Hebert, P. D. N. 2018. The distribution and abundance of parasites in harvested wildlife from the Canadian North: A review. Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada*, p. 20–30. DOI: 10.35298/pkc.2018.03

acanthocephalans (thorny-headed worms); acari (ticks); insects (lice, fleas, and flies); and pentastomids (tongue worms). The most diverse groups are roundworms and tapeworms (Cestoda), with 80 and 78 species respectively. Birds are the group of vertebrates with the largest number of recorded parasite species, with 115; although many of these taxa were extraterritorial, they are also likely to occur in the Canadian North because of the high mobility of their hosts. Mammal and fish parasite records comprise 88 and 59 species respectively. It is interesting that no parasites have been documented for the Arctic hare, *Lepus arcticus* (Table 1). Among the 248 species of parasites, only 133 are represented by voucher specimens in existing collections. Importantly, no vouchers are available for parasites of polar bears or walruses from the Canadian North. Conversely, there are numerous records in these collections for species that have not been reported in the literature (Appendix 2, https://www.polardata.ca/pdcsearch/?doi_id=12962).

Fishes

The Arctic char (*Salvelinus alpinus*) is the fish species with the largest number (35) of known parasite species (Table 1). Reflecting its anadromous nature, these parasites include some species acquired in the marine environment and others in fresh water. However, its high diversity of parasites also reflects the fact that the Arctic char is, by far, the most intensively studied fish species in the Arctic. Other Arctic fish species are known to host from 5 to 18 parasite species.

Several of these species are of zoonotic importance. Larvae of roundworms in the genus *Contracaecum* and other related genera live in mesenteries and body cavity of fish. However, once a fish is dead, they rapidly migrate into the muscle, reducing the quality of the meat, and some species represent a potential source of infection for humans if they ingest raw, smoked, or undercooked fish (McCarthy and Moore 2000). Although in most cases the infection is asymptomatic, patients may experience nausea, vomiting, diarrhea, abdominal pain, and hypersensitivity reactions (Jenkins et al. 2013). In the same way, larval tapeworms of the genus *Diphyllobothrium* live in the muscle or viscera of fish and are transmitted to their definitive host when ingested. In the wild, the definitive hosts are polar bears, marine mammals, and other carnivores, but humans can be infected by zoonotic diphyllobothriid tapeworms if they eat raw or undercooked fish (Desdevises et al. 1998). Diphyllobothrosis is rarely associated with clinical disease and is not considered a major public health problem in Canada (Jenkins et al. 2013). High infection levels with *Diphyllobothrium* species can also inhibit gonadal development in fish, reducing their reproductive potential (Gallagher et al. 2009).

Monogenean and copepod parasites on fish gills can cause delays in growth and sexual maturation as well as hypoxia in heavy infections (Gallagher, et al. 2009; Winger et al. 2008). Although no epizootic events caused by

Table 1: Number of macroparasite species known from species of harvested wildlife in the Canadian North.

Host species	# of parasite species						
	P	N	A	C	Ac	I	TOTAL
Fish							
Salvelinus alpinus (Arctic char)	21	8	4	2			35
Salvelinus namaycush (Lake trout)	9	2		1			12
Coregonus clupeaformis (Whitefish)	8	2		2			12
Boreogadus saida (Polar cod)	11	4	2	1			18
Arctogadus glacialis (Arctic cod)	2 (2)	2 (2)	1 (1)				5 (5)
Birds							
Cepphus grylle (Black guillemot)	2 (1)					3	5 (1)
Uria aalge (Common murre)	11	6			2	4 (1)	23 (1)
Anas acuta (Northern pintail)	7 (6)	2 (2)					9 (8)
Anser albifrons (Greater white-fronted goose)	2 (2)						2 (2)
Anser caerulescens (Snow goose)	5 (1)	5				1	11 (1)
Anser rossii (Ross's goose)					1 (1)		1 (1)
Branta canadensis (Canada goose)	6 (5)	5 (4)			1 (1)	2	14 (10)
Branta bernicla (Brant goose)	2 (2)	1 (1)				1	4 (3)
Clangula hyemalis (Long-tailed duck)						1	1
Cygnus colombianus (Tundra swan)	2 (2)	1 (1)			1 (1)	4 (2)	8 (6)
Histrionicus histrionicus (Harlequin duck)	3 (3)						3 (3)
Somateria spectabilis (King eider)	6 (6)	1 (1)	1			1	9 (7)
Gavia pacifica (Pacific loon)	4 (4)						4 (4)
Gavia stellata (Red-throated loon)	4 (4)	1					5 (4)
Gavia adamsi (Yellow-billed loon)	2 (2)						2 (2)
Lagopus lagopus (Willow ptarmigan)	7 (6)	6 (5)			5 (5)	7 (5)	25 (21)
Lagopus muta (Rock ptarmigan)	6 (6)	3 (3)				2	11 (9)
Mammals							
Rangifer tarandus (Caribou)	7	15			3	2	27
Ovibos moschatus wardi (Muskox)	5	12					17
Vulpes lagopus (Arctic fox)	4	4					8
Canis lupus (Wolf)	12	5					17
Gulo gulo (Wolverine)		1					1
Ursus arctos horribilis (Grizzly bear)	2	5					7
Ursus maritimus (Polar bear)	2	3					5
Cystophora cristata (Hooded seal)		3					3
Erignathus barbatus (Bearded seal)		3				1	4
Pagophilus groenlandicus (Harp seal)	1	7					8
Phoca vitulina (Harbour seal)	1 (1)	8 (2)	1 (1)			1 (1)	11 (5)
Pusa hispida (Ringed seal)	5	9	3			1	18
Odobenus rosmarus (Walrus)		2					2
Delphinapterus leucas (Beluga whale)	2	5					7
Monodon monoceros (Narwhal)		1					1

Tetraonchus spp. or *Salmincola* spp. have been reported in the Canadian North, these species are present in this area, and it is important to be aware of their potential effects on fish populations.

Birds

A total of 99 species have been documented in Arctic birds, although 55 of these records are extraterritorial (Appendix 1, https://www.polardata.ca/pdcsearch/?doi_id=12962). The list is dominated by tapeworms and roundworms of the digestive tract, and no parasites of zoonotic importance have been reported. Mortality events in geese have been documented in other regions, in which heavy infections with roundworms of the upper digestive tract (*Echinuria uncinata*) in Poland (Cornwell 1963), heartworms (*Sarconema eurycea*) in the United States (Holden and Sladen 1968), or schistosomes (*Anserobilharzia brantae*) in southern Ontario (Wojcinski et al. 1987) were reported, and might have contributed to mortality. A negative correlation between parasite community burden and host fitness parameters has contributed to cyclic declines in willow ptarmigan (*Lagopus lagopus*) populations in Norway (Holmstad et al. 2005). The flea *Ceratophyllus vagabundus* had a negative impact on reproductive success in geese colonies in Nunavut (Harriman and Alisauskas 2010), and may be a vector for bacterial diseases for Arctic wildlife (Mascarelli et al. 2015). The parasite fauna on guillemots and murres has been intensively studied in the Arctic and used as a model for host-parasite coevolution (Hoberg 1986) and as markers of ecological change (Muzaffar et al. 2005). Considering the migratory behaviour of ducks and geese, it is important to monitor their parasite fauna, as they might introduce emerging pathogens (Amundson et al. 2016).

Mammals

The caribou, *Rangifer tarandus*, and muskoxen, *Ovibos moschatus*, both harbour diverse parasite assemblages, 27 and 17 species respectively. These parasites include various taxonomic groups, including digeneans, tapeworms, roundworms, flies, and mites, although the roundworms are most diverse. Nematodes of the subfamily Trichostrongylinae (*Ostertagia*, *Marshallagia*, and *Teladorsagia*) are common parasites of the abomasum (the fourth stomach compartment in ruminants), where they can cause serious effects on nutrition when present in high numbers. However, these two ungulate species are most seriously impacted by internal parasites, such as the lungworms (*Dictyocaulus*, *Varestrongylus*, *Protostrongylus*, and *Umingmakstrongylus*) or the muscle-dwelling worms (*Parelaphostrongylus*). Infection with these parasites can affect respiratory function and interfere with neurological or muscular function, increasing susceptibility to predation (Kutz et al. 2012).

Caribou and muskoxen are natural intermediate hosts for the tapeworms *Echinococcus canadensis*, *Taenia hydatigena*, and *T. krabbei*, which complete their life cycle in canids (dogs, foxes, and wolves) and release their eggs with the feces of the definitive host. *Taenia hydatigena* and *T. krabbei* have not been reported as a cause of zoonoses (various diseases that can be transmitted from animals to humans); in contrast, *Echinoccoccus canadensis* is the cause of a recurrent zoonosis in the Arctic. People, like caribou and muskoxen, get infected when eggs of this tapeworm are accidentally ingested (Jenkins et al. 2013).

Crustaceans of the subclass Pentastomida are parasites of the nasal cavity of vertebrates. *Linguatula arctica* is a common parasite of the nasal cavity of caribou in particular; this species has a direct life cycle, but the eggs are expelled with mucus and ingested by other ungulates when grazing. There has been no report of serious effects on infected animals (Kutz et al. 2012).

Parasitic flies commonly attack caribou; larvae of *Hypoderma tarandi* (warbles) and *Cephenemyia trompe* (nose bots) can cause damage by burrowing into the skin or growing in the nasal cavity respectively. Harassment by these parasitic dipterans can reduce feeding time and lead to diminished feed intake, reduced summer weight gain, decreased lactation, lower calf weight, and poorer overall condition, which may influence reproductive success. There is an increasing concern about *Hypoderma tarandi* causing a zoonosis, as it can cause migratory dermal swellings and ophthalmomyasis interna (invasion of the eye) in humans, often causing loss of the eye (Lagacé-Wiens et al. 2008; Kan et al. 2013). Mites of the genus *Chorioptes* have been reported to cause epidermal and dermal inflammatory lesions in the outer ear canal of caribou and hair loss on the legs of muskoxen, reducing the overall condition of the animals (Kutz et al. 2012).

Wolves (*Canis lupus*) and Arctic foxes (*Vulpes lagopus*) harbour 17 and 8 species of parasites respectively, with tapeworms and roundworms being most diverse. Digeneans of the genus *Alaria* have been recorded from the boreal ecozone only, as their life cycle involves intermediate hosts (amphibians) that are not yet present in the Arctic. *Echinococcus multilocularis* and *E. canadensis* have particularly important implications for human health. These tapeworms use foxes, wolves, and dogs as their definitive hosts; *E. multilocularis* uses rodents (voles and lemmings) as an intermediate host, while *E. canadensis* uses cervids (moose and caribou) (Jenkins et al. 2013). People get infected when they accidentally ingest eggs that have been shed in carnivore feces, developing cystic echinococcosis (usually in the lungs and liver) or alveolar echinococcosis (usually in the liver), which may be fatal if not detected and treated early (Jenkins et al. 2013; Gesy et al. 2014). Echinococcosis, or hydatid disease, can be asymptomatic for several years until cysts grow enough to trigger clinical signs — abdominal pain and nausea if the liver is the affected organ, or cough, chest pain, and shortness of breath if the lungs are affected (WHO 2018). Feeding dogs with the viscera of infected caribou or moose can facilitate human infection, given the closeness of dogs to humans. Molecular studies have revealed several strains of *E. canadensis* (G8 and G10) and *E. multilocularis* (Asian, European, and North American strains) in North America, which is important because there may be differences in their levels of infectivity and pathogenicity for humans (Thompson et al. 2006; Gesy et al. 2014).

Toxascaris leonina is an intestinal roundworm of canids and felids that has a direct life cycle and is not considered zoonotic; the zoonotic canine ascarid Toxocara canis appears to have low prevalence in the Canadian North (Jenkins et al. 2013). Other important parasite species recorded from foxes, wolves, and wolverines are roundworms of the genus T*richinella*. These roundworms possess a unique life history, as a single vertebrate species serves as both definitive and intermediate host. Adults live in the intestine, where females produce larvae that migrate to the skeletal muscle. Transmission to other species, including humans, can occur when the original host is eaten. The genus *Trichinella* includes nine species and three genotypes (Krivokapich et al. 2012); only T. nativa (T2) and genotype T6 have been reported from northern Canada (Larter et al. 2011). These roundworms have been recorded from many vertebrate species in the Arctic, including carnivores (polar and grizzly bears, Arctic fox, wolf, and dog) and pinnipeds (walrus and ringed seal) (Appendix 1, https://www.polardata.ca/pdcsearch/?doi_id=12962). People get infected through the consumption of raw or undercooked meat from an infected animal, producing trichinellosis, which causes edema, fever, rash, and myalgia. Outbreaks of human trichinellosis remain a public health concern in the Canadian North (Jenkins et al. 2013).

Few parasitological studies have been conducted with bears in the Canadian North, and some of the studies in polar bears are from captive specimens. Seven parasite species have been recorded from grizzly bears and five from polar bears (four of these from captive specimens). The tapeworm Diphyllobothrium ursi completes its life cycle in the intestine of bears after they feed on fish, the intermediate host. Humans can accidentally be infected with this species by consuming raw or undercooked fish (Jenkins et al. 2013). *Trichinella* spp. roundworms (*T. nativa* and genotype T6) are common in both grizzly and polar bears in the Canadian North (Brown et al. 1949; Choquette et al. 1969; Gajadhar and Forbes 2010; Jenkins et al. 2013; Larter et al. 2011; Rah et al. 2005; Smith 1978; Thorshaug and Rosted 1956), and at least one human outbreak has been linked to the consumption of grizzly bear (Houzé et al. 2009).

The ringed seal has considerably more species of parasites (18) than the other seal species, which have from 3 to 11 species (Table 1). Among the parasite species are the heartworms (*Acanthocheilonema spirocauda*) and the lungworms (*Otostrongylus circumlitus* and *Parafilaroides hispidus*), which can cause damage to the lungs in heavy infections, especially to seal pups (Measures and Gosselin 1994; Ondreka 1989). Both tapeworms and roundworms occur in the intestinal tract as *Anisakis* sp., *Contracaecum osculatum* and *Pseudoterranova decipiens*. Larvae of these ascarids are transmitted by fish, and humans can become infected by consuming raw or undercooked fish (Jenkins et al. 2013).

Sucking lice (family Echinophthiriidae) are mostly specialized on seals. *Echinophthirius horridus*, in particular, is found on many seal species in the Northern Hemisphere, including the ringed seal. It is most prevalent on young animals because of their higher body temperature and thinner skin. There is evidence that this ectoparasite is the intermediate host for the heartworm *Acanthocheilonema spirocauda*, which often has serious consequences for young seals (Geraci et al. 1981; Leidenberg et al. 2007).

At least 16 species of parasites (tapeworms, roundworms, and acanthocephalans) have been reported from walrus in the Bering Strait (Rausch et al. 2007). However, few studies have been completed in the Canadian North, where only two species of parasites have been recorded, an ascarid, *Pseudoterranova decipiens*, from the stomach and *Trichinella* sp. in muscle. This latter species has caused several outbreaks of trichinellosis in humans after eating walrus meat (Jenkins et al. 2013).

The beluga whale hosts at least seven species of parasites in the Canadian North, five roundworms and two digeneans. No negative effects have been linked to the presence of these parasites, even from heavy infections of the lungworm *Pharurus pallasii* (Houde et al. 2003). The ascarids recorded from beluga whale stomachs (*Anisakis simplex*, *Contracaecum osculatum*, and *Pseudoterranova decipiens*) are caused by the ingestion of fish. Humans can be infected with Anisakis sp. and *Contracaecum* sp. by eating raw or undercooked fish, but there is no evidence of zoonotic infection with *Pseudoterranova*. The only parasite species recorded for the narwhal is the lungworm *Halocercus monoceris*, which caused the death of a specimen collected at Baffin Island after it had been held captive in the Vancouver Aquarium (MacNeill et al. 1975).

Community considerations

This review highlights the need to extend the study of the parasites that infect the primary animal species of country food in the Canadian North. Although some host species (Arctic char and caribou) have been intensively investigated, most have received little attention. For example, there are no records of parasites from the Arctic hare, and information on parasite assemblages for many birds (ducks, geese, and ptarmigan) is only available for other regions. More detailed information on parasite communities is particularly important as climate change raises the possibility that new parasite species will colonize the region. For example, the winter tick (*Dermacentor albipictus*) is an abundant and serious pest of moose (*Alces alces*) in southwestern Canada, causing anemia and hair loss (Samuel 1989). The northernmost distribution of *D. albipictus* was documented just south of 60º N (Wilkinson 1967); in recent years a range expansion to the Arctic, presumably induced by climate warming and/or anthropogenic translocation, has been documented (Kutz et al. 2009). This is of particular interest because caribou and moose are highly susceptible to winter ticks, and in captive conditions, infections can be severe (Welch et al. 1990).

Another example is the lone star tick (*Amblyomma americanum*), which primarily parasitizes deer, but also a wider variety of mammals and a wide variety of birds. This tick may transmit various bacterial infections (Kollars et al. 2000) and causes an allergy to red meat (Commins et al. 2013). This species of tick was formerly restricted to the eastern United States and northern Mexico, but its range is expanding north and west in the US (Scott et al. 2001). It is improbable that this temperate tick species will establish in the Arctic in the near future.

To address the current information gap, it is essential to assemble a comprehensive inventory of the parasite fauna for the most important food species in the North. Studies then need to be expanded to obtain baseline information on the prevalence and abundance of each parasite species on each host species. This information will make it possible to monitor long-term trends in parasite populations, which in turn make it possible to anticipate epizootic or zoonotic outbreaks that could seriously affect their host species and take preventive actions (Brooks et al. 2004). In the past, it was difficult to accurately identify very many parasite species, because the distinguishing morphological characters are not present in all parasite stages, and this requires technical expertise, which is increasingly unavailable. In some cases, accurate identification of a parasite is of high importance because of differential ability to infect and cause disease in humans (e. g., differences among species and strains of the tapeworm genus Echinococcus). Because of such factors, it is essential to employ an identification method that is fast and accurate, a need that is met by DNA barcoding (Hebert et al. 2003). Once the reference barcode for a species is established, identifications can be made by simply comparing DNA sequences from newly collected material with the references, in most cases. There are some cases where intraspecific variation or lack of variation in the particular fragment of DNA used as the standard barcode (for animals, frequently the COI mtDNA locus) can obscure the results; in these cases, sequencing of additional fragments may solve this problem (if sufficient sequence databases exist). Building a DNA barcode library for the parasites from wildlife harvested in the Canadian North will also contribute to voucher collections and sequence databases, providing better coverage of Canadian biodiversity.

Conclusions

Parasites are key components of ecosystems and sentinels of environmental change. Nevertheless, there are large gaps of knowledge about parasites of wildlife harvested as country food in the Canadian North, especially for some species of fish, birds, and carnivores. Documenting and monitoring the presence and distribution of parasites in the Canadian North will be of great value in the development of effective action plans for coping with emerging infectious diseases linked to climate change. The early detection of a novel parasite in an ecosystem or an abrupt fluctuation in the population of a common parasite species gives important insights, not only about one host species, but also about the intermediate host populations, including trophic relationships. Detection is a key step towards mitigation of the effects of climate and landscape change on parasite communities in the Canadian North.

Acknowledgements

We thank Rebecca Davidson and one anonymous reviewer for their careful revision of the manuscript. Virginia León-Règagnon thanks Programa de Apoyo para la superación del Personal Académico, UNAM–2016 for support during a sabbatical stay at the University of Guelph. Logistic and financial support was provided by Polar Knowledge Canada.

References

Aboriginal Affairs and Northern Development Canada. 2007–2008. Government of Canada program for international polar year: Highlights and achievements. 79 pp.

Amundson, C. L., Traub, N. J., Smith-Herron, A. J., and Flint, P. L. 2016. Helminth community structure in two species of Arctic-breeding waterfowl. *International Journal for Parasitology: Parasites and Wildlife* 5:263–272.

Baldridge, G. D., Scoles, G. A., Burkhardt, N. Y., Schloeder, B., Kurtti, T. J., and Munderloh, U. G. 2009. Transovarial transmission of *Fracisella*-like endosymbionts and *Anaplasma phagocytophilum* variants in Dermacentor albipictus (Acari: Ixodidae). *Journal of Medical Entomology* 46:625–632.

Brooks, D. R., Hoberg, E. P., Boeger, W. A., Gardner, S. L., Galbreath, K. E., Herczeg, D., Mejía-Madrid, H. H., Rácz, S. E., and Dursahinhan, A. T. 2014. Finding them before they find us: Informatics, parasites, and environments in accelerating climate change. *Comparative Parasitology* 81:155–164.

Brown, M., Cronk, B., DeSinner, F., Green, J.E., Gibbons, J.E., and Kuitunen-Ekbaum, E. 1949. A note on trichinosis in animals of the Canadian Northwest Territories. Canadian Public Health Association. 40:20–21.

Choquette, L. P. E., Gibson, G. G., and Pearson, A. M. 1969. Helminths of the grizzly bear, *Ursus arctos* L., in northern Canada. *Canadian Journal of Zoology* 47:167–170.

Commins, S. P. and Platts-Mills, T. A. 2013. Tick bites and red meat allergy. *Current Opinion in Allergy and Clinical Immunology* 13:354–359.

Cornwell, G. 1963. Observations on waterfowl mortality in southern Manitoba caused by *Echinuria uncinata* (Nematoda, Acuariidae). *Canadian Journal of Zoology*. 41:699–703.

Davidson, R., Simard, M., Kutz, S., Kapel, C., Hamnes, I., and Robertson, L. 2011. Arctic parasitology: Why should we care?. *Trends in Parasitology* 27:239–245.

Desdevieses, Y., Arthur, J. R., and Pellerin-Massicotte, J. 1998. Parasites of anadromous Arctic char (*Salvelinus alpinus* L.) from two sites in Ungava Bay (Quebec, Canada). *Journal of the Helminthological Society of Washington* 55:87–90.

Gajadhar, A. A. and Forbes, L. B. 2010. A 10-year wildlife survey of 15 species of Canadian carnivores identifies new hosts or geographic locations for *Trichinella* genotypes T2, T4, T5, and T6. *Veterinary Parasitology* 168:78–83.

Gallagher, C. P., Dick, T. A, Babaluk, J. A., and Reist, J. D. 2009. Parasite community of Arctic char, *Salvelinus alpinus*, from Lake Hazen and Craig Lake, Quittinrpaaq National Park, Nunavut. Canadian Technical Report of Fisheries and Aquatic Sciences 2854:1–24.

Gesy, K. M., Schurer, J. M., Massolo, A., Liccioli, S., Elkin, B. T., Alisauskas, R., and Jenkins, E. J. 2014. Unexpected diversity of the cestode *Echinococcus multilocularis* in wildlife in Canada. *International Journal of Parasitology: Parasites and Wildlife* 3:81–87.

Harriman, V. B., and Alisauskas, R. T. 2010. Of fleas and geese: The impact of an increasing nest ectoparasite on reproductive success. *Journal of Avian Biology* 41:573–579.

Hebert, P. D. N., Cywinska, A., Ball, S. L., and deWaard, J. R. 2003. Biological identifications through DNA barcodes. *Proceedings of the Royal Society B: Biological Sciences* 270:313–321.

Hoberg, E. P. 1986. Evolution and historical biogeography of a parasite-host assemblage: *Alcataenia* spp. (Cyclophyllidea: Dilepididae) in Alcidae (Charadriiformes). *Canadian Journal of Zoology* 64:2576–2589.

Hoberg, E. P. 2010. Invasive processes, mosaics, and the structure of helminth parasite faunas. *Revue Scientifique et Technique*, International Office of Epizootics. 29:255–272.

Hoberg, E. P. and Brooks, D. R. 2008. A macroevolutionary mosaic: Episodic host-switching, geographical colonization, and diversification in complex host-parasite systems. *Journal of Biogeography* 35:1533–1550.

Hoberg, E. P., Galbreath, K. E., Cook, J. A., Kutz, S. J., and Polley, L. 2012a. Northern host-parasite assemblages: History and biogeography on the borderlands of episodic climate and environmental transition. *Advances in Parasitology* 79:1–97.

Hoberg, E. P., Kutz, S. J., Galbreath, K. E., and Cook, J. 2003. Arctic biodiversity: From discovery to faunal baselines; Revealing the history of a dynamic ecosystem. *Journal of Parasitology* 89:S84–S95.

Hoberg, E. P., Polley, L., Jenkins, E. J., Kutz, S. J., Veitch, A. M., and Elkin, B.T. 2008. Integrated approaches and empirical models for the investigation of parasitic diseases in northern wildlife. *Emerging Infectious Diseases* 14:10–17.

Holden, B. L. and Sladen, W. J. L. 1968. Heartworm, Sarconema eurycerca, infection in whistling swans, *Cygnus columbianus*, in Chesapeake Bay. *Bulletin of the Wildlife Disease Association* 4:126–128.

Holmstad, P. R., Hudson, P. J., and Skorping, A. 2005. The influence of a parasite community on the dynamics of a host population: A longitudinal study on willow ptarmigan and their parasites. *Oikos* 111:377–391.

Houde, M., Measures, L. N., and Huot, J. 2003. Experimental transmission of *Pharurus pallasii* (Nematoda: Metastrongyloidea), a lungworm of the cranial sinuses of the beluga whale (*Delphinapterus leucas*), to fish. *Canadian Journal of Zoology* 81:364–370.

Houzé, S., Ancelle, T., Matra, R., Boceno, C., Carlier, Y., Gajadhar, A. A., and Dupouy-Camet, J. 2009. Trichinellosis acquired in Nunavut, Canada, in September 2009: Meat from grizzly bear suspected. *Eurosurveillance* 14:1–2.

Hudson, P. J., Dobson, A. P., and Lafferty, K. D. 2006. Is a healthy ecosystem one that is rich in parasites?. *Trends in Ecology and Evolution* 21:381–385.

Jenkins, E. J., Castrodale, L. J., Rosemond, S. J. C., Dixon, B. R., Elmore, S. A., Gesy, K. M., Hoberg, E. P., Polley, L., Schurer, J. M., Simard, M., and Thompson, R. C. A. 2013. Tradition and transition: Parasitic zoonoses of people and animals in Alaska, Northern Canada, and Greenland. *Advances in Parasitology* 82:33–204.

Kan, B., Asbakk, K., Fossen, K., Nilssen, A., Panadero, R., and Otranto, D. 2013. Reindeer warble fly: Associated human myasis, Scandinavia. *Emerging Infectious Diseases* 19:831–832.

Kollars, T. M. J., Oliver, J. H., Durden, L. A., and Kollars, P. G. 2000. Host associations and seasonal activity of *Amblyomma americanum* (Acari: Ixodidae) in Missouri. *Journal of Parasitology* 86:1156–1159.

Krivokapich, S. J., Pozio, E., Gatti, G. M., Gonzalez P. C. L., Ribicich, M., Marucci, G., La Rosa, G., and Confalonieri, V. 2012. *Trichinella patagoniensis* n. sp. (Nematoda), a new encapsulated species infecting carnivorous mammals in South America. *International Journal for Parasitology* 42:903–910.

Kutz, S. J., Ducrocq, J., Verocai, G., Hoar, B., Colwell, D., Beckmen, B., Polley, L., Elkin, B., and Hoberg, E. 2012. Parasites of ungulates of Arctic North America and Greenland: A view of contemporary diversity, ecology, and impact in a world under change. *Advances in Parasitology* 79:99–252.

Kutz, S. J., Jenkins, E. J., Veitch, A. M., Ducrocq, J., Polley, L., Elkin, B., and Lair, S. 2009. The Arctic as a model for anticipating, preventing, and mitigating climate change impacts on host parasite interactions. *Veterinary Parasitology* 163:217–228.

Lagacé-Wiens, P. R. S., Dookeran, R., Skinner, S., Leicht, R., Colwell, D. D., and Galloway, T. D. 2008. Human ophthalmomyasis interna caused by Hypoderma tarandi, Northern Canada. *Emerging Infectious Diseases* 14:64–66.

Larter, N. C., Forbes, L. B., Elkin, B., and Allaire, D. G. 2011. Prevalence of *Trichinella* spp. in black bears, grizzly Bears, and wolves in the Dehcho Region, Northwest Territories, Canada, including the first report of *T. nativa* in a grizzly bear from Canada. *Journal of Wildlife Diseases* 47:745–749.

Leidenberg, S., Harding, K., and Harkonen, T. 2007. Phocid seals, seal lice, and heartworms: A terrestrial host-parasite system conveyed to the marine environment. *Diseases of Aquatic Organisms* 77:235–253.

MacNeill, A. C., Neufeld, J. L., and Webster, W. A. 1975. Pulmonary nematodiasis in a narwhal. *Canadian Veterinary Journal* 16:53–55.

Mascarelli, P. E., Elmore, S. A., Jenkins, E. J., Alisauskas, R. T., Walsh, M., Breitschwerdt, E.B., and Maggi, R. G. 2015. Vector-borne pathogens in Arctic foxes, *Vulpes lagopus*, from Canada. *Research in Veterinary Science* 99:58–59.

McCarthy, J. and Moore, T. A. 2000. Emerging helminth zoonoses. *International Journal for Parasitology* 30:1351–1360.

Measures, L. N. and Gosselin, J. F. 1994. Helminth parasites of ringed seal, *Phoca hispida*, from northern Quebec, Canada. *Journal of the Helminthological Society of Washington* 61:240–244.

Muzaffar, S. B., Hoberg, E. P., and Jones, I. L. 2005. Possible recent range expansion of *Alcataenia longicervica* (Eucestoda: Dilepididae) parasitic in murres *Uria* spp. (Alcidae) into the North Atlantic. *Marine Ornithology* 33:189–191.

Ondreka, D. K. 1989. Prevalence and pathology of nematode infections in the lungs of ringed seals (*Phoca hispida*) of the western Arctic of Canada. *Journal of Wildlife Diseases* 25:218–224.

Polley, L., Hoberg, E., and Kutz, S. 2010. Climate change, parasites, and shifting boundaries. *Acta Veterinaria Scandinavica* 52-S1:1–5.

Rah, H., Chomel, B. B., Kasten, R. W., Hew, C. H., Farver, T. B., Follmann, E. H., Garner, G. W., and Amstrup, S. C. 2005. Serosurvey of selected zoonotic agents in polar bears (*Ursus maritimus*). *Veterinary Record* 156:7–13.

Rausch, R. L. 1974. Tropical problems in the Arctic: Infectious and parasitic diseases, a common denominator. *In* Industry and tropical health VIII, Pelizzon, R. (ed.), Harvard School of Public Health, Cambridge. pp. 63–70.

Rausch R., George, J.C., and Brower, H.K. 2007. Effect of climatic warming on the Pacific Walrus, and potential modification of its helminth fauna. *Journal of Parasitology* 93:1247–1251.

Samuel, W. M. 1989. Locations of moose in northwestern Canada with hair loss probably caused by the winter tick, *Dermacentor albipictus* (Acari: Ixodidae). *Journal of Wildlife Diseases* 25:436–439.

Scott, J. D., Fernando, K., Banerjee, S. N., Durden, L. A., Byrne, S. K., Banerjee, M., Mann, R. B., and Morshed, M. C. 2001. Birds disperse Ixodid (Acari: Ixodidae) and *Borrelia burgdorferi*-infected ticks in Canada. *Journal of Medical Entomology* 38:493–500.

Smith, H. J. 1978. Status of trichinosis in bears in the Atlantic provinces of Canada 1971–1976. Canadian *Journal of Comparative Medicine* 42:244–245.

Thompson, R. C., Boxell, A. C., Ralston, B. J., Constantine, C. C., Hobbs, R. P., Shury, T., and Olson, M. E. 2006. Molecular and morphological characterization of *Echinococcus* in cervids from North America. *Parasitology* 132:439–447.

Thorshaug, K. and Rosted, A. F. 1956. Researches into the prevalence of trichinosis in animals in Arctic and Antarctic waters. *Nordisk Veterinaermedicin* 8:115–129.

Wilkinson, P. R. 1967. The distribution of *Dermacentor* ticks in Canada in relation to bioclimatic zones. *Canadian Journal of Zoology* 45:517–537.

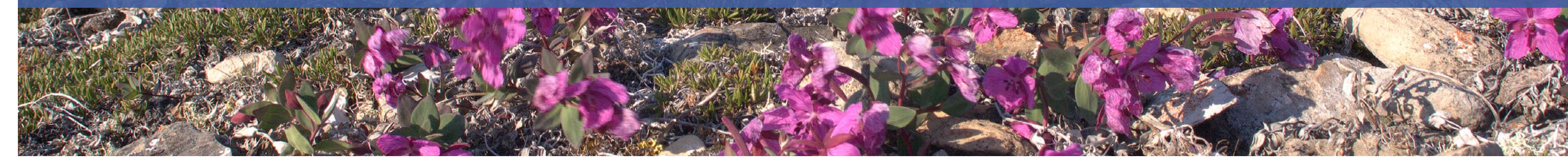
Winger, A. C., Kanck, M., Kristoffersen, R., and Knudsen, R. 2008. Seasonal dynamics and persistence of *Gyrodactylus salaris* in two riverine anadromous Arctic char populations. *Environmental Biology of Fishes* 83:117–123.

Wojcinski, Z. W., Barker, I. K., Hunter, D. B., and Lumsden, H. 1987. An outbreak of schistosomiasis in Atlantic Brant geese, *Branta bernicla hrota*. *Journal of Wildlife Diseases* 23:248–255.

World Health Organization. 2018. Echinococcosis. Available from http://www.who.int/news-room/fact-sheets/detail/echinococcosis [accessed 30 September 2018].

FIRE IN THE ARCTIC:

The effect of wildfire across diverse aquatic ecosystems of the Northwest Territories



Suzanne E. Tank[1*], David Olefeldt[2], William L. Quinton[3], Christopher Spence[4], Nicole Dion[5], Caren Ackley[3], Katheryn Burd[2], Ryan Hutchins[1], and Samson Mengistu[1]

[1] *Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada*

[2] *Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada*

[3] *Centre for Cold Regions and Water Science, Wilfred Laurier University, Waterloo, Ontario, Canada*

[4] *Environment and Climate Change Canada, Saskatoon, Saskatchewan, Canada*

[5] *Water Resources Department, Government of Northwest Territories, Yellowknife, Northwest Territories, Canada*

* *suzanne.tank@ualberta.ca*

Abstract

During the summer of 2014, the southern Northwest Territories (NWT) experienced an unprecedented wildfire season, with burned areas spread across two ecoregions (the Taiga Plains and Taiga Shield) and a landscape underlain by a mosaic of permafrost coverage, vegetation type, and previous fire history. Our study was conducted across the Dehcho, Tłı̨chǫ-Wek'èezhii, and Akaitcho Regions of the NWT, which encompass the most significantly burned areas from the 2014 fire season. Within these regions, we worked in paired burned–unburned catchments on the Taiga Plains and Taiga Shield to examine responses to fire within ground and surface waters. We additionally examined water quality across a series of 50 catchments that were stratified across ecoregion and by fire history, and varied in within-catchment characteristics such as wetland extent. This sampling scheme — which covers as significant a range of landscape variability as possible — is allowing us to differentiate the effects of wildfire from other landscape variables that cumulatively impact aquatic ecosystem health. While wildfire had a clear effect on the chemical composition of pore waters, this effect was diminished at the stream outlet and at the landscape scale. Rather than having an overriding effect on water quality, wildfire appears to be one of many landscape variables that act in concert to determine water quality in the southern NWT.

Introduction

During the summer of 2014, the southern Northwest Territories (NWT) experienced an unprecedented wildfire season, with a burn footprint that spread across two ecoregions (the Taiga Plains and Taiga Shield), and a landscape underlain by a mosaic of permafrost coverage, vegetation type, and previous fire history (Fig. 1, 2). Our study was conducted across the Dehcho, Tłı̨chǫ-

Suggested citation:

Tank, S.E., Olefeldt, D., Quinton, W.L., Spence, C., Dion, N., Ackley, C., Burd, K., Hutchins, R., and Mengistu, S., 2018. Fire in the Arctic: The effect of wildfire across diverse aquatic ecosystems of the Northwest Territories. Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 31–38. DOI: 10.35298/pkc.2018.04*

Wek'èezhii, and Akaitcho Regions, which encompass the most extensively burned areas from the 2014 fire season. We undertook a tiered *hillslope - to catchment - to landscape* approach to understand how the effects of fire cascade through aquatic ecosystems, from the smallest scale (hillslope pore waters) to the largest scale (the southern NWT landscape). To do this, we coupled intensive measurements of pore-water and stream-outlet chemistry in selected burned and unburned catchments with a series of extensive measurements across 50 catchments that varied by within-catchment fire extent, ecoregion, and characteristics such as wetland extent (Fig. 2). This design is allowing us to explore the mechanistic effects of wildfire on stream water quality, while also differentiating these effects from other landscape variables that cumulatively affect the characteristics of aquatic ecosystems.

Previous research has shown that wildfire can substantially alter the chemistry of downslope freshwater ecosystems. For example, combustion of organic layers and loss of vegetation can increase nutrients (Betts and Jones 2009; Fig. 2) and toxins like mercury (Kelly et al. 2006) but decrease organics (Betts and Jones 2009) in recipient aquatic ecosystems, although results can also be mixed (e.g., Olefeldt et al. 2013). Following wildfire, the burn scar is also more susceptible to permafrost thaw than adjacent undisturbed areas, because the loss of tree canopy allows greater energy loading at the ground surface, while the blackened ground also absorbs more energy. The resultant deepening of active layers can further affect the chemistry of water flowing from land to streams, as soils that were previously frozen become available for contact with water. In On the Taiga Shield, soils typically consist of organic horizons down to bedrock, with thin mineral soils. In contrast, deep peatlands are abundant on the Taiga Plains, but the underlying soil is composed of thick mineral tills. Thus, the effect of wildfire might be expected to fundamentally differ between these two regions, with increases in organics where deepening or lengthening flow paths enable access to organic soils, and increases in inorganic nutrients (e.g., nitrate and phosphate) and ions where water is routed through inorganic horizons. Deepening thaw can also encourage the establishment of *taliks* (i.e., a perennially thawed layer between the overlying active layer and underlying permafrost; Gibson 2017), which can enable the flow of water and associated chemical constituents throughout the year. These wildfire-associated changes in water chemistry are important because changes in within-stream concentrations of nutrients, organics, sediments, and contaminants may in turn alter the ecological functioning of freshwater systems (see, for example, Minshall et al. 2001, Allen et al. 2005, Kelly et al. 2006, Smith et al. 2011, and Silins et al. 2014).

Figure 1: Images of burned regions on the Taiga Shield (a; Boundary Creek) and Taiga Plains (b; Spence Creek); potential nutrient effects downstream of a burn scar (c; algal mats in Notawohka Creek that are not common elsewhere); and recovery from burn two years post-fire (d; stream draining to Lac La Martre, Whatì).

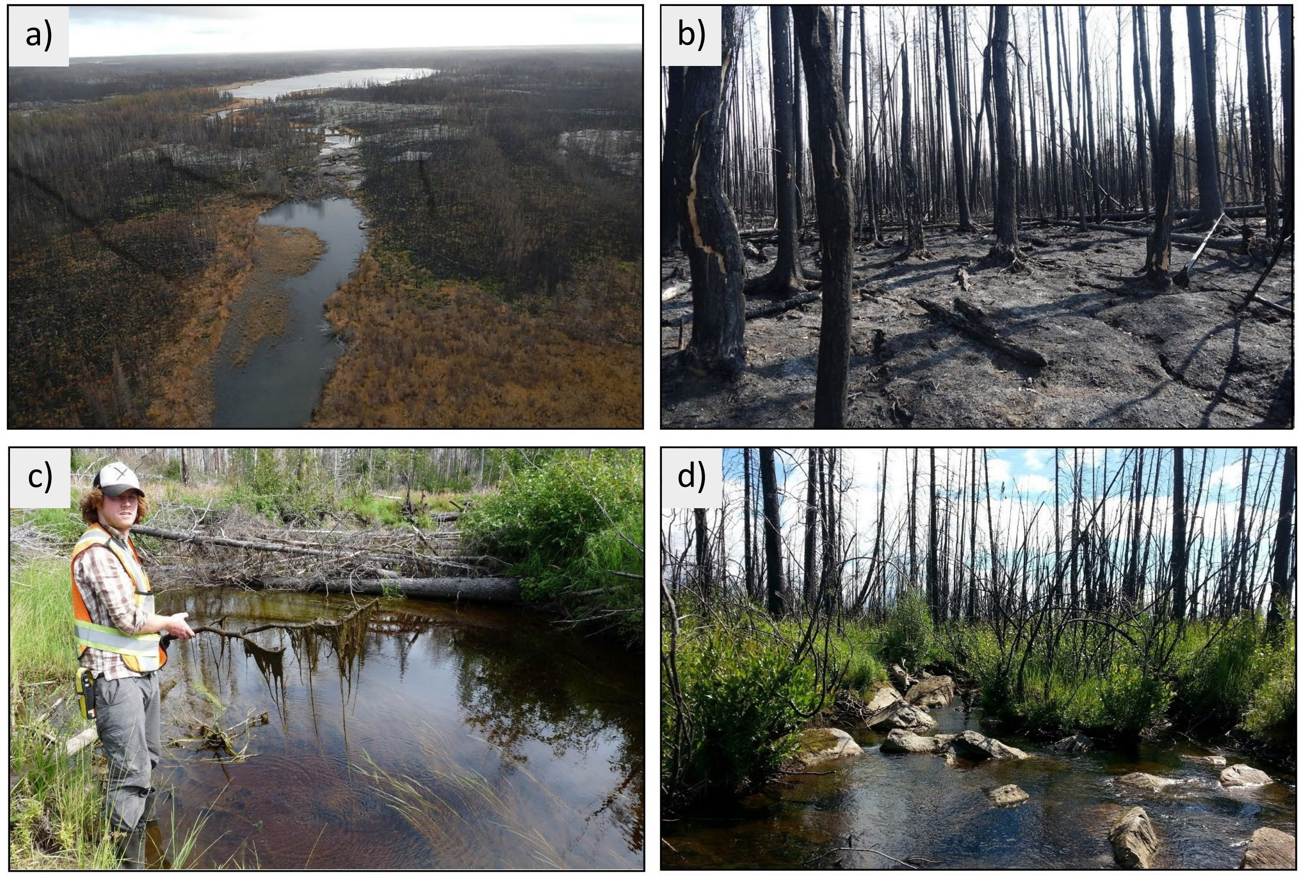
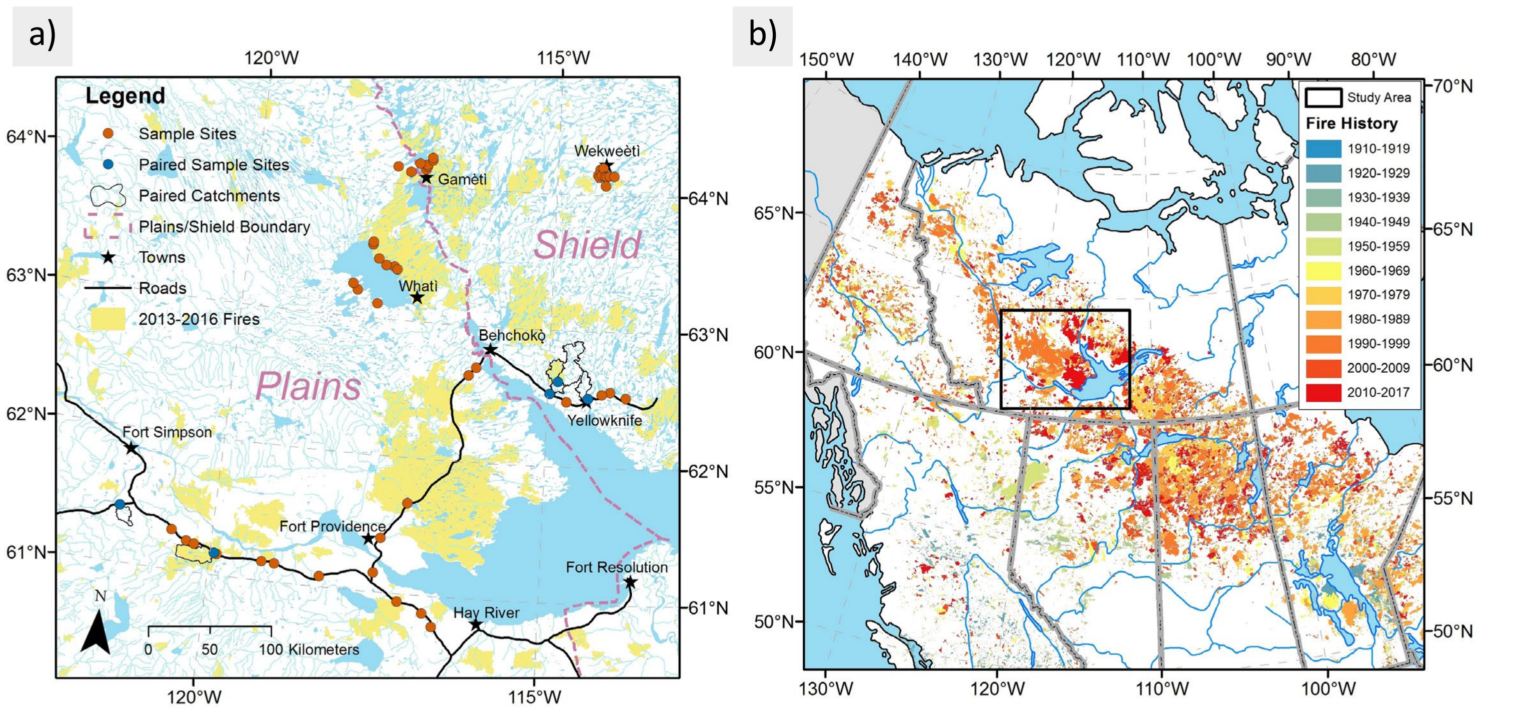


Figure 2: (a) Sampling locations superimposed on the 2013–2016 fire perimeters (the paired burned-unburned catchments that were the focus of our intensive measurements are indicated in blue; the 50 synoptic sampling locations are indicated in orange) and (b) Fire history for the region, with the more detailed area of panel (a) indicated by a box.



Although the influence of wildfire on water chemistry has been investigated in some northern hillslope systems and within small Subarctic catchments, including in Alaska (Betts and Jones 2009, Koch et al. 2014), it has been poorly studied in the NWT. This is of concern from an NWT-specific perspective, because the Subarctic landscape is composed of a diversity of region-specific landscape features, which may act cumulatively and in distinct ways to influence downslope water chemistry. Given that wildfire frequency is increasing in northern Canada (Kasischke and Turetsky 2006; Flannigan et al. 2009), it is imperative that we undertake region-specific assessments of its effect on aquatic and other ecosystem components. Such targeted assessments will help to predict how fire might affect aquatic ecosystems across diverse landscape types, and thus, also understand changes in natural resources (food webs, fish) and infrastructure (drinking water) that might result.

Methods

Our cascading *hillslope - to catchment - to landscape* design took a three-tiered approach. First, we worked within targeted burned and unburned sites on the Taiga Plains (Notawohka and Scotty Creeks) and Taiga Shield (Boundary and Baker Creeks; Fig. 2) to examine the effects of wildfire on ground temperature, snow accumulation, frost-table depth, and the chemical composition of water available for runoff downslope to streams (i.e., mobile pore water). Second, we undertook frequent measures of stream-outlet chemistry within these paired catchments, to better understand the fine-scale response of catchments to wildfire. Finally, we undertook a synoptic survey of 50 burned and unburned catchments (Fig. 2) during June-July of 2016 and May-June of 2017, with a subset of these catchments being additionally sampled in August and September of 2016. This work was carried out as a collaborative effort between academic researchers, Federal government scientists, and aquatic scientists from the Government of the Northwest Territories (GNWT). Residents of the communities of Jean Marie River, Fort Simpson, Whatì, Wekweètì, and Gamètì were also integral to project planning and sample collection, as outlined below.

To target water available for movement downslope, pore-water samples were collected at the water table using MacroRhizon samplers (0.15 µm pore size; Rhizosphere Research Products, Wageningen, the Netherlands) (Burd et al. 2018) or by filtering water collected from pit samples (Sartorius 0.45 µm). Samples for this component were analyzed at the University of Alberta, either in individual laboratories or at the CALA-accredited (ISO 17025) Biogeochemical Analytical Service Laboratory (BASL). Our targeted paired burned-unburned catchments were sampled weekly for four weeks following the onset of flow in the spring, and monthly thereafter in each of 2015, 2016, and 2017. Paired catchment-outlet samples were collected using protocols established by the GNWT Water Resources Division, and the samples were analyzed at the GWNT Taiga Environmental Laboratory. Pre-existing (Baker Creek, unburned) and project-specific (Boundary Creek, burned) meteorological stations on the Taiga Shield collected air temperature, relative humidity, net radiation, wind speed, and rainfall, and were coupled with frost-table measurements in burned and unburned terrains in Baker, Boundary, and Scotty Creeks.

For our 50-site synoptic surveys, we accessed all possible streams located near Highways 1 and 3, and additionally worked with the communities of Whatì, Wekweètì, and Gamètì to access stream sites from the lakes on which these communities are located. Sampling locations were stratified across burned and unburned terrains. Chemistry samples were collected following standard protocols, field-filtered (pre-combusted Whatman GF/F filters, 0.7 µm pore size), and stored chilled, in the dark, for later analysis at the University of Alberta's BASL.

To allow us to calculate constituent export and normalize total constituent flux by watershed area (i.e., yield; Tank et al. 2012), we also measured discharge at each site. Of the four paired catchment sites, discharge data are actively collected by the Water Survey of Canada at Scotty and Baker Creeks. For Boundary and Notawohka Creeks, discharge was determined using in-stream pressure transducers and the development of stage-discharge rating curves. For the 50 synoptic sites, point discharge was measured concurrent with water chemistry sample collection using a FlowTracker2 hand-held Acoustic Doppler Velocimeter (SonTek Inc., San Diego, CA) and the cross-sectional area-velocity method.

Catchment boundaries were delineated from a 20-metre digital elevation model (http://geogratis.gc.ca), using ArcGIS (10.5) with the hydrology toolbox. Catchment-outlet coordinates acquired during sample collection were used as pour points for the delineations. Catchment delineations were used to derive catchment characteristics, including slope and percent cover of various landscape types (Canadian Land Cover, circa 2000 (Vector) - GeoBase Series). Catchment fire scar areas were extracted from National Fire Database GIS layers provided by the Canadian Forest Service.

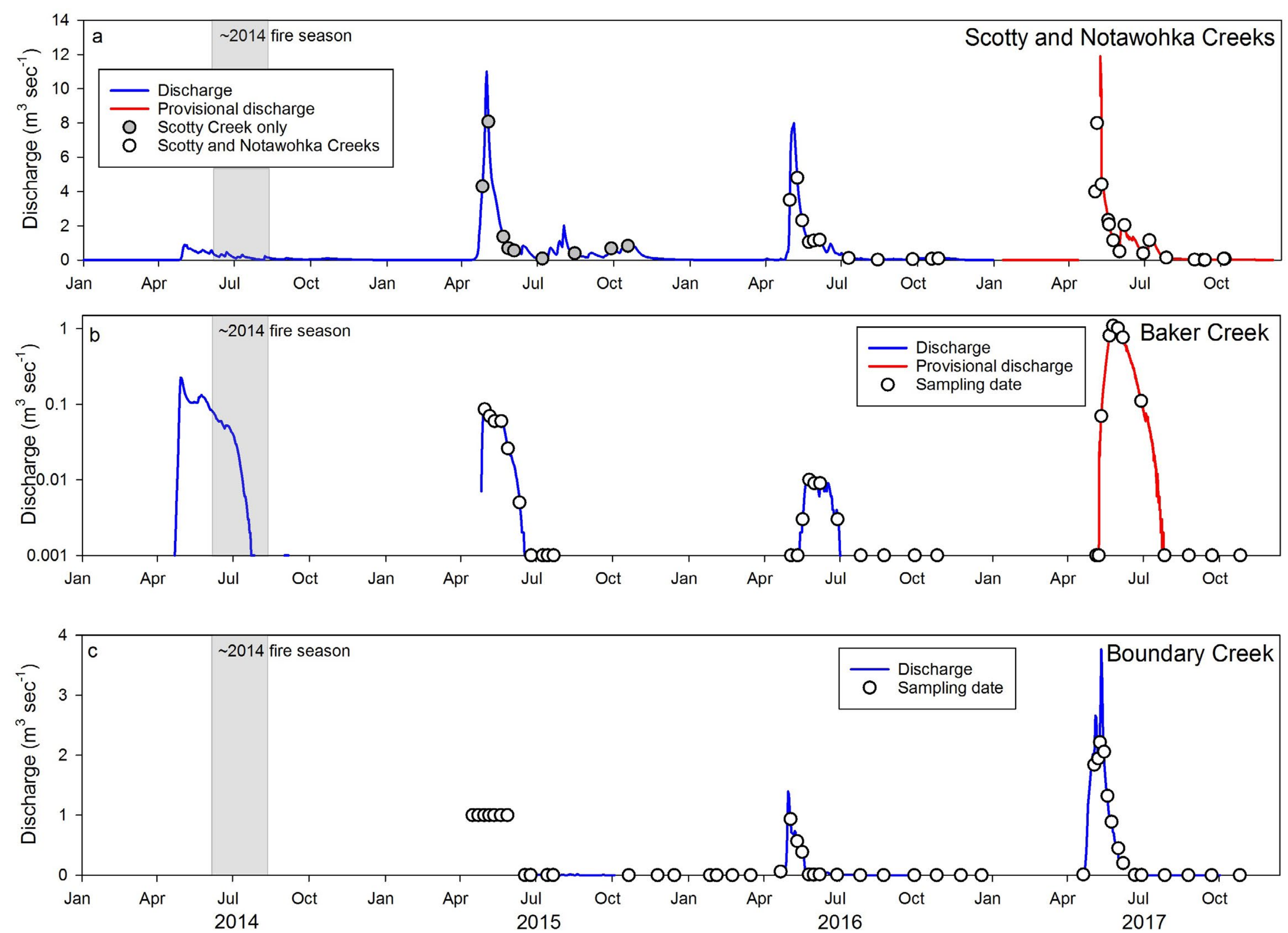
Preliminary results

Collaboration with government partners and community assistance allowed us to achieve strong temporal and spatial coverage in our sampling efforts. Our paired catchment work successfully captured initial spring flows in 2015, which represented the first runoff pulse following the 2014 wildfire season (Fig. 3). Subsequent sampling enabled excellent coverage of the spring freshet in 2016 and 2017, and continued collection throughout each of the three sample years in cases where flows continued under ice (e.g., Boundary Creek; Fig. 3). Our synoptic survey effectively captured a range of landscapes within each of the Taiga Plains and Taiga Shield. For example, the within-watershed coverage of lakes and wetlands varied from levels near zero percent to greater than 80% of the catchment, while mean catchment slope — an important regulator of water residence on the landscape — varied across a substantial gradient in each of the two ecoregions (Fig. 4). Wildfire-affected catchments were well distributed across these landscape gradients, and encompassed about half of the catchments surveyed. Shield and Plains regions differed in their proportion of lakes, wetlands, and mean catchment slope, following the underlying differences between these physiographic regions.

Burned and unburned sites clearly differed in their water chemistry at the plot scale, but these differences appeared to diminish with movement through the hydrologic network (Fig. 5). For example, using dissolved organic carbon (DOC) as a model chemical species, our results show elevated DOC concentrations in burned pore waters of the Taiga Plains (Fig. 5a), but that this signal dampens at the catchment outlet, where the increase in DOC export over the full season in paired burned-unburned catchments was much more modest (Fig. 5b). Across the 50 synoptic sites that were sampled mid-summer 2016, this difference disappears, with no overriding effect of wildfire on DOC concentration (Fig. 5c) across the wide variety of watersheds that we sampled (Fig. 4). This overall finding of weak to no effects of wildfire at the synoptic scale was consistent across other key water-quality parameters. For example, nutrients, which drive primary production at the base of aquatic food webs (total dissolved nitrogen; total dissolved phosphorus; Fig. 5d and 5e), and ions, which can be indicative of changing (deepening and/or transitioning to perennial) flow paths on land (using calcium as an example; Fig. 5f), also showed no difference between burned and unburned catchments. Although in some cases there were differences in chemical constituents between ecoregions (e.g., Fig. 5f), wildfire did not override other variable landscape characteristics to cause a clear effect on water chemistry across the synoptic sites that we investigated.

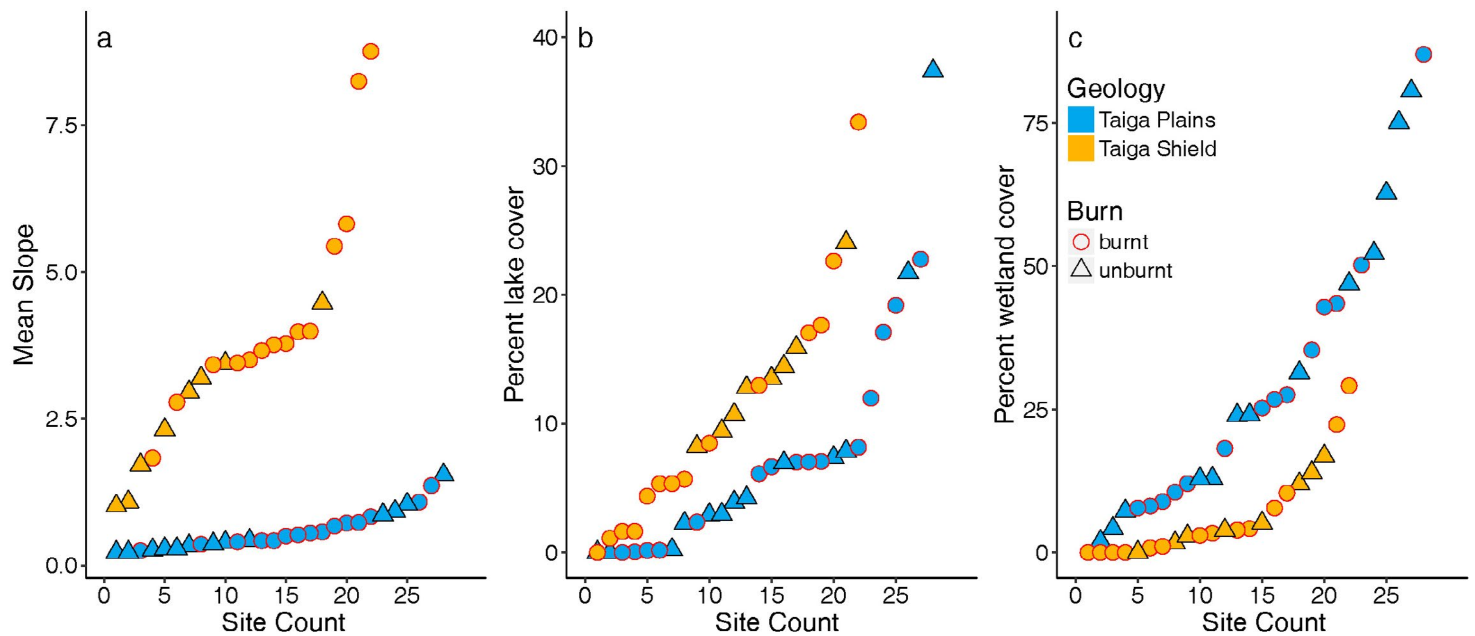
It is worth noting that the synoptic study results that we present were collected during relatively low-flow mid-summer conditions, when connectivity between streams and the landscape can be low, and also two summers following the 2014 burn season (i.e., for samples collected during summer 2016; Fig. 1d shows a typical catchment two years post-fire). Our paired catchment work did suggest that constituents including DOC, ions, and selected metals were elevated in the spring runoff period immediately post-fire (see, for example, the evidence of increased nutrients immediately post-fire in Fig. 1c). However, this effect was short lived. Across the southern NWT, it appears that wildfire is but one of

Figure 3: Sampling dates (circles) superimposed on discharge hydrographs for the paired catchment sites to show sample coverage across varying flow conditions: (a) Scotty and Notawohka Creeks sampling dates superimposed on the Scotty Creek hydrograph, (b) Baker Creek sampling dates superimposed on the Baker Creek hydrograph (note log scale), and (c) Boundary Creek sampling dates superimposed on the Boundary Creek hydrograph.



POLAR KNOWLEDGE Aqhaliat

Figure 4: The distribution of synoptic sampling sites across a range of landscape conditions (each point shows an individual catchment): (a) slope, (b) percent lake cover, and (c) percent wetland cover for sites on the Taiga Plains (blue) and Taiga Shield (orange). Within each landscape type, burned sites are shown as circles outlined in red and unburned sites are shown as triangles outlined in black. Individual sample sites are ordered by increasing coverage of the within-catchment landscape condition; note the differences in scale on the y-axis.



many landscape controls on the functioning of aquatic ecosystems, and that this disturbance does not have an overriding effect on water quality at the multi-year scale.

Conclusions

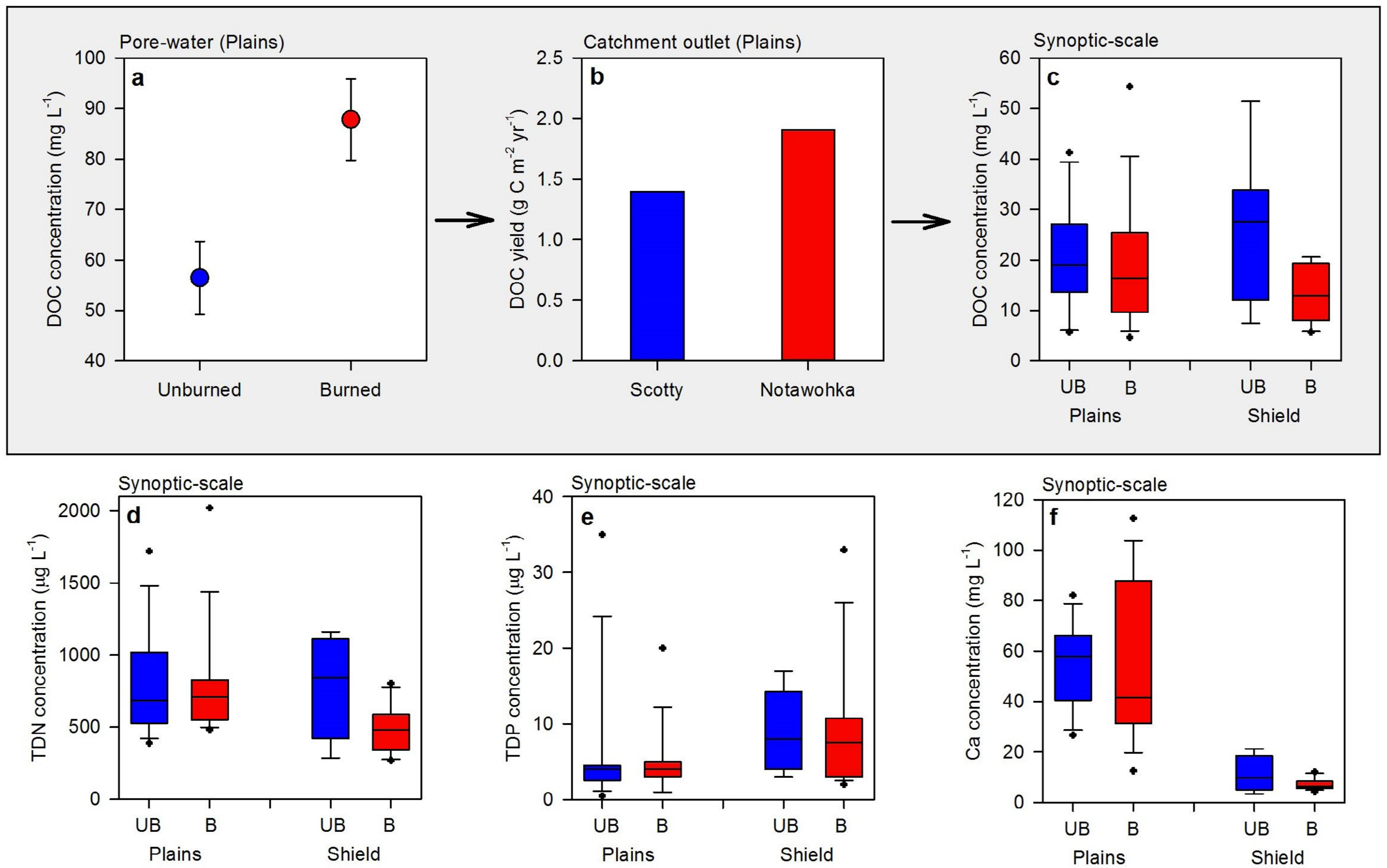
The results of this project indicate that fire does not have a long-lasting effect on downstream water chemistry in streams across the southern NWT. This result is somewhat contradictory to studies from Subarctic Alaska and non-permafrost affected boreal regions in Alberta, which have shown clear effects of wildfire on stream water nutrients, organics, and toxins (Betts and Jones 2009, Kelly et al. 2006). Instead, this research may add to other emerging studies that are showing aquatic ecosystems to be relatively resilient to the effects of wildfire in their catchments (e.g., Lewis et al. 2014), and suggests that — over yearly time scales — the effects of wildfire are relatively small compared to other spatially variable drivers of water chemistry, and therefore difficult to differentiate from background variability.

Community considerations

The 2014 wildfire season burned 3.4 million hectares of land (Fig. 1). Because the area of disturbance was largely in the more densely inhabited southern NWT, fires affected the majority of NWT residents, resulting in road closures, multiple community evacuations, and significant concern about the ecological and human health effects of this catastrophic disturbance (Baltzer and Johnstone 2015). This concern led to a collaborative workshop that assembled Territorial government scientists and managers, academic scientists, and Federal government scientists. It was this workshop that was the genesis for this work. Our research occurred in direct collaboration with staff of the GNWT Water Resources Division, who helped with the study design and played a key role in field efforts. Their central involvement in these efforts has been critical for ensuring that Territorial priorities are being met as part of this research effort.

We used a variety of avenues to enable linkages between our research and local communities. Our sampling in the Tłı̨chǫ region (summers of 2016 and 2017) was facilitated by local community directors, and occurred in association with local guides who were instrumental in finalizing site-selection decisions and assisting with our access to local lands. Work in the Dehcho occurred in collaboration with members of the Jean Marie River First Nation who assisted with sampling a local stream (Spence Creek) that burned extensively during the 2014 fire. We have found these partnerships to be critical for ensuring that sampling efforts are appropriately targeting areas of

Figure 5: Constituent concentrations and yields (area-normalized exports) across burned (B) and unburned (UB) sites, for sampling at scales ranging from pore waters to the broad landscape: (a) pore-water concentrations of dissolved organic carbon (DOC) in burned and unburned plots of the Scotty Creek catchment; (b) catchment-outlet DOC yields for Scotty Creek (>99.8% unburned) and Notawohka Creek (>90% burned) through the entire 2016 season; (c) synoptic-scale DOC concentrations from across the 50 catchments for samples collected during summer 2016; and (d, e, f) synoptic-scale total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), and dissolved calcium (Ca) concentrations, all from summer 2016.



concern. These linkages are also ongoing in associated projects.

Acknowledgements

This research would not have occurred without the assistance of community directors in the Tłı̨chǫ region (April Alexis and Shirley Dokum, Whatì; Gloria Ekendia-Gon, Gamètì; Adeline Football, Wekweètì) and Chief Gladys Norwegian in Jean Marie River. These individuals identified community members who were instrumental in guiding our use of local lands and assisting us to identify streams within each of the communities where we conducted this work. Wayne and Lynn McKay were also critical for our paired sampling on the Taiga Plains. In the Tłı̨chǫ region, we were fortunate to have Lloyd Bishop (Whatì), Alfred Arrowmaker (Gamètì), and William Quitte (Wekweètì) directly involved in our sampling efforts. In Jean Marie River, we were fortunate to have Derek Norwegian, Bill Norwegian, Douglas Norwegian, Richard Sanguez, Stanley Sanguez, and Borris Sanguez assisting with our sampling efforts. Funding for this research was from Polar Canada, the Cumulative Impacts Monitoring Program, the Campus Alberta Innovates Program, and the Natural Sciences and Engineering Research Council of Canada, as well as in-kind support from the GNWT.

References

Allen, E.W., Prepas, E.E., Gabos, S., Strachan, W.M.J., and Zhang, W.P. 2005. Methyl mercury concentrations in macroinvertebrates and fish from burned and undisturbed lakes on the Boreal Plain. *Canadian Journal of Fisheries and Aquatic Sciences* 62:1963–1977. doi: 10.1139/f05-103.

Baltzer, J. and Johnstone, J. 2015. The 2014 NWT fires: Developing a research framework. Workshop report provided to the Government of the Northwest Territories. 11 pp.

Betts, E.F. and Jones, J.B. Jr. 2009. Impact of wildfire on stream nutrient chemistry and ecosystem metabolism in boreal forest catchments of interior Alaska. *Arctic, Antarctic, and Alpine Research* 41:407–417. doi: 10.1657/1938-4246-41.4.407.

Burd, K., Tank, S.E., Dion, N., Quinton, W.L., Spence, C., Tanentzap, A.J., and Olefeldt, D. 2018. Seasonal shifts in export of DOC and nutrients from burned and unburned peatland-rich catchments, Northwest Territories, Canada. *Hydrology and Earth System Science 22:4455–4472. Available at* https://doi.org/10.5194/hess-22-4455-2018*, 2018.*

Flannigan, M., Stocks, B., Turetsky, M., and Wotton M. 2009. Impacts of climate change on fire activity and fire management in the circumboreal forest. *Global Change Biology* 15:549–560. doi: 10.1111/j.1365-2486.2008.01660.x.

Gibson, K. 2017. Long-term effects of wildfire on permafrost stability and carbon cycling in northern peatlands. M.Sc. thesis, University of Alberta. 98 pp.

Kasischke, E.S. and Turetsky, M.R. 2006. Recent changes in the fire regime across the North American boreal region: Spatial and temporal patterns of burning across Canada and Alaska. *Geophysical Research Letters* 33:L09703. doi: 10.1029/2006gl025677.

Kelly, E.N., Schindler, D.W., St. Louis, V.L., Donald, D.B., and Vlaclicka, K.E. 2006. Forest fire increases mercury accumulation by fishes via food web restructuring and increased mercury inputs. *Proceedings of the National Academy of Science* 103:19380–19385. doi: 10.1073/pnas.0609798104.

Koch, J.C., Kikuchi, C.P., Wickland, K.P., and Schuster, P. 2014. Runoff sources and flow paths in a partially burned, upland boreal catchment underlain by permafrost. *Water Resources Research* 50:8141–8158. doi: 10.1002/2014wr015586.

Lewis, T.L., Lindberg, M.S., Schmutz, J.A., and Bertram, M.R. 2014. Multitrophic resilience of boreal lake ecosystems to forest fires. *Ecology* 95:1253–1263.

Minshall, G.F., Brock, J.T., Andrews, D.A., and Robinson, C.T. 2001. Water quality, substratum, and biotic responses of five central Idaho (USA) streams during the first year following the Mortar Creek fire. *International Journal of Wildland Fire* 10:185–199. doi: 10.1071/wf01017.

Olefeldt, D., Devito, K.J., and Turetsky, M.R. 2013. Sources and fate of terrestrial dissolved organic carbon in lakes of a Boreal Plains region recently affected by wildfire. *Biogeosciences* 10:6247–6265. doi: 10.5194/bg-10-6247-2013.

Silins, U., Bladon, K.D., Kelly, E.N., Esch, E., Spence, J.R., Stone, M., et al. 2014. Five-year legacy of wildfire and salvage logging impacts on nutrient runoff and aquatic plant, invertebrate, and fish productivity. *Ecohydrology* 7:1508–1523. doi: 10.1002/eco.1474.

Smith, H.G., Sheridan, G.J., Lane, P.N.J., Nyman, P., and Haydon S. 2011. Wildfire effects on water quality in forest catchments: A review with implications for water supply. *Journal of Hydrology* 396:170–192. doi: 10.1016/j.jhydrol.2010.10.043.

Tank, S.E., Frey, K.E., Striegl, R.G., Raymond, P.A., Holmes, R.M., McClelland, J.W., et al. 2012. Landscape-level controls on dissolved carbon flux from diverse catchments of the circumboreal. *Global Biogeochemical Cycles* 26:GB0E02. doi: 10.1029/2012GB004299.

ARCTIC MARINE ECOLOGY BENCHMARKING PROGRAM:

Monitoring biodiversity using scuba

Jessica Schultz[1], Jeremy Heywood[1 *], Donna Gibbs[1], Laura Borden[1], Danny Kent[1], Mackenzie Neale[1], Crystal Kulcsar[1], Ruby Banwait[1], and Laura Trethewey[1]

[1] Ocean Wise Conservation Association, Vancouver, British Columbia, Canada

** jeremy.heywood@ocean.org*

The Ocean Wise Conservation Association (OWCA, ocean.org) is a global ocean conservation organization focused on protecting and restoring our world's oceans.

Abstract

Building on the catalogue of data gathered during the 2015 and 2016 Nearshore Ecological Surveys, the 2017 Arctic Marine Ecology Benchmarking Program (AMEBP) collected biodiversity and abundance data on marine algae, invertebrates, and fish species using scuba diving at selected sites near Cambridge Bay, Nunavut, in the summer of 2017. The project served as a pilot study to assess scuba diving survey modes (transect vs. taxon) and make recommendations for future research and monitoring efforts. This paper is a summary of the 2017 Arctic Marine Ecology Benchmarking Program Final Report (available on request).

Introduction

Reliable baseline data and ongoing monitoring are essential for developing a full understanding of the changes underway in Canada's Arctic, thereby enabling the development of effective management strategies and conservation plans. The nearshore ecosystem is a key part of the larger marine ecosystem, because it is where most direct human impact, such as boating, hunting, and harvesting, takes place. However, there have been very few scuba diving surveys of nearshore marine flora and fauna in the Canadian Arctic, which faces increasing risk due to climate change, invasive species, and increased human activity. This project addresses this significant gap by establishing baseline biodiversity data and initiating long-term nearshore monitoring near Cambridge Bay, Nunavut.

Methods

Scuba diving

Dives were completed by Ocean Wise divers holding a Scientific Diver Level II rating, as defined by the Canadian Association for Underwater Science (caus.ca) Standard of Practice for Scientific Diving, and were planned using DCIEM Air Diving Tables as no-decompression dives using compressed air. No more than two dives per day per diver were undertaken. Dives met the requirements of the Nunavut Occupational Health and Safety Regulations: Part 20, Diving Operations. The project included a combination of shore- and boat-based dives.

Suggested citation:

Schultz, J., Heywood, J., Gibbs, D., Borden, L., Kent, D., Neale, M., Kulcsar, C., Banwait, R., and Trethewey, L. 2018. Arctic Marine ecology benchmarking program: Monitoring biodiversity using scuba. Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 39–45. DOI: 10.35298/pkc.2018.05*

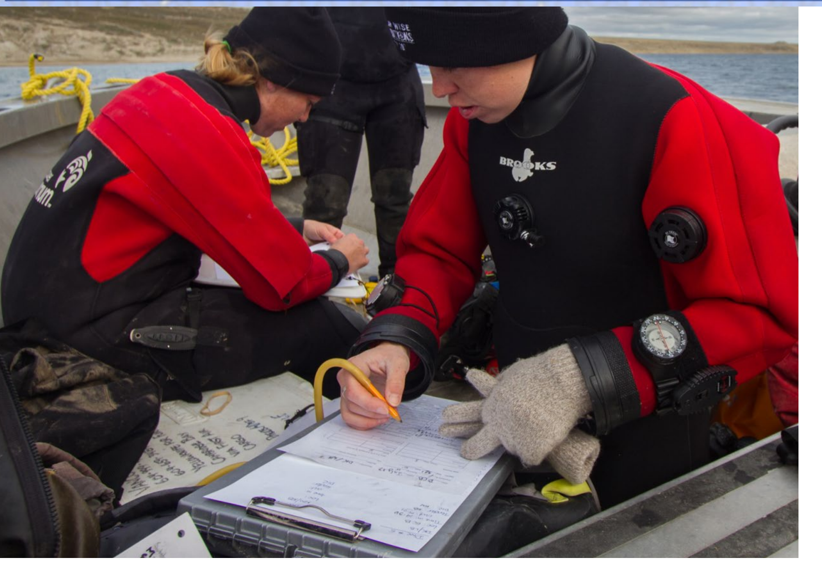


Figure 1: Ocean Wise dive team members making notes after a survey dive.

Benchmarking surveys (transect dives)

Appropriate sites were randomly selected from a list of previously explored sites. Two sites from each of three sampling areas — Cambridge Bay, West Arm, and the Findlayson Islands — were selected (Table 1).

Four benchmarking survey transect dives (Fig. 2) were conducted at each of the six sites. Transects were centred on the site coordinates, and followed a bearing on the 10-metre-depth contour parallel to shore (as closely as was practical). Each transect dive consisted of a fish transect, an invertebrate and algae swath survey, and a habitat survey, following the methods of the subtidal monitoring protocols of the Pacific Rim National Park Reserve (Jennifer Yakimishyn: personal communication, 2015), with the exception that the taxa recorded were specific to Nunavut (Table 2).

Roving biodiversity surveys (taxon dives)

At least one taxon dive was conducted at each transect site. Divers navigated using the bottom topography, recorded all organisms observed (to the lowest taxonomic level possible), and estimated the approximate abundance of each.

Data analysis

Community composition and habitat characteristics

We calculated the mean and standard deviation of fish, invertebrate, and algae counts for each transect survey. Species composition was summarized by comparing the three sampling areas using an Analysis of Similarity (ANOSIM; Primer 6) of the square root transformed abundance data. Habitat characteristics among the three areas were compared using mean proportions and standard deviation. We also totalled the number of each species observed at each site using the taxon dive method, and calculated the average abundance following the methods in Marliave et al. 2011.

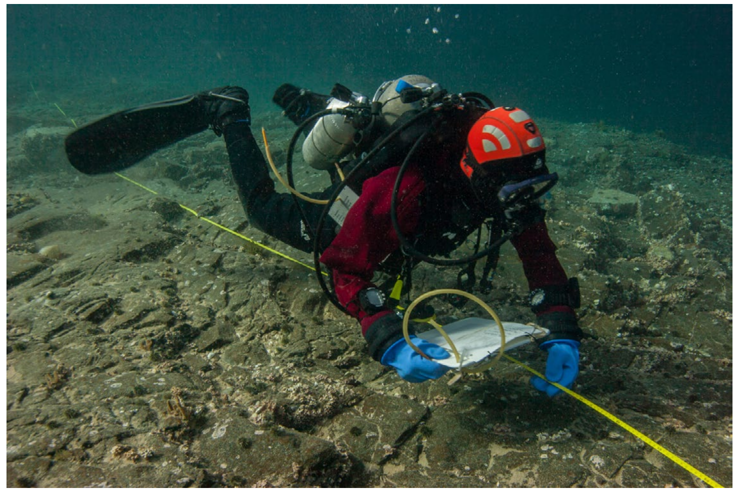


Figure 2: Ocean Wise diver completes transect dive.

Table 1: Pilot survey monitoring sites near Cambridge Bay.

Site name	Area	Substrate	Latitude	Longitude
West of 5 Island	Cambridge Bay	mud, dropstones	69.0687	-105.1967
Cape Colborne Inside	Cambridge Bay	sand, silt, mud, slope	68.9668	-105.2304
Old Camping Spot	West Arm	silt, boulders, flat	69.1104	-105.0761
West Arm BCB	West Arm	sloping shale, mud	69.1093	-105.1717
Starvation Cove Point	Findlayson Islands	sand, cobble	69.1492	-105.9233
Unnamed Island 1 South End	Findlayson Islands	cobble, boulders	69.0938	-105.8989

Power analysis of benchmarking sampling design

Green urchins (*Strongylocentrotus droebachiensis*) were used as a case study species to evaluate the benchmarking survey sampling design as a tool for long-term ecological monitoring. Urchins are an abundant and ecologically important indicator species (Coyer et al. 1993; Estes and Duggins 1995; Chen and Hunter 2003; DFO 2013). Following the methods in Green and McLeod 2016, we conducted a linear mixed-effects-model power analysis to assess the power of the sampling design. Two types of power analyses were conducted using the model output: the first was to determine the number of monitoring years needed under the present sampling design (six sites with four transects each) to detect a 25% change in the urchin population with 80% power, and the second was to determine the number of study sites required to detect a 25%, 50%, and 2×SD change in the population from one year to the next (i.e., with two years of sampling; Munkittrick et al. 2009).

Comparison of transect and taxon dive methods

To illustrate the different potential applications of each method, species accumulation curves of the benchmark transects were compared with those of the taxon dive technique. Species accumulation curves were constructed by ordering surveys chronologically and then plotting the cumulative number of species detected with each additional survey for both transect surveys and roving biodiversity surveys.

Results and discussion

Benchmarking surveys (transect dives)

Community composition and habitat characteristics

The most abundant taxa were Arctic saxicave, green urchins, and tube-dwelling anemones (Table 2). The abundance of Arctic saxicave should be interpreted with

Table 2: The mean abundance of taxa enumerated in 60 m^2 transects (n = 24) at six sites in Cambridge Bay, in order of abundance.

Scientific name	Common name	Mean Abundance	Standard Deviation
Hiatella arctica	Arctic saxicave	520.6	725.4
Strongylocentrotus droebachiensis	Green urchin	430.6	583.6
Pachycerianthus borealis	Tube dwelling anemone	223.2	330.7
Various	Non-sessile polychaetes	12	18.3
Utricina spp.	Urticina anemones	11.7	17.5
Hormathia spp.	Rugose anemone	8.9	23.1
Psolus fabricii	Scarlet sea cucumber	2.4	4.3
Buccinum spp.	Buccinum snail	1.1	2.3
Dendronotis spp.	Dendronotid nudibranchs	0.8	2.7
Cottoidea	Sculpins	0.8	0.9
Hyas coarctatus	Arctic lyre crab	0.6	1
Various	Solitary tunicates	0.6	1.1
Stichaeidae	Pricklebacks	0.5	0.9
Various	Bladed red algae	0.3	0.5
Cucumaria frondosa	Giant black sea cucumber	0.2	0.6
Icasterias panopla	Red spiky sea star	0.2	0.6
Saccharina latissima	Sugar kelp	0.2	0.5
Various	Non-sessile nemerteans	0.2	0.5
Lebbeus polaris	Polar lebbeid shrimp	0.1	0.4
Urasterias lincki	Frilled sea star	0.1	0.3
Various	Dorid nudbranchs	0	0.2
Zoarcidae	Eelpouts	0	0.2

caution because the species was challenging to identify when buried in the sediment.

Overall, there was no difference in the community composition among sites in Cambridge Bay, West Arm, and the Findlayson Islands (ANOSIM: $R = 0.557$, $p = 0.10$). The average abundance of invertebrates and algae was higher in the Findlayson Islands than in the other two areas, but the abundance of fish was low (less than two individuals per 60 m^2) in all areas (Fig. 3).

The habitat of most sites was characterized by low-relief and low-complexity mud or sediment. At all sites, most intersection points had no organic cover (84.4% ±14.3 SD) and had smooth habitat complexity (score = 0; 70.8% ±30.8 SD). However, the Findlayson Island sites had proportionately less sediment compared with the other areas, a greater proportion of cobbles and boulders, and a lower proportion of zero-complexity points (38.3% ±25.4 SD; Fig. 4). Almost all points along all transects had a relief value of <1m.

Differences in abundance of fish, invertebrates, and algae between the Findlayson Islands and the other areas could be attributed to differences in habitat characteristics. The Findlayson Islands are more exposed to tidal current than the other two areas, exposing a higher proportion of hard substrate habitat, such as cobble and boulders.

Power analysis

The sampling design used in this pilot study would be adequate to detect large (e.g., 50% or 2×SD) changes in the abundance of individual species from one year to the next, but a smaller effect size (e.g., 25%) would require several years of sampling and/or more survey sites. With six sites (24 transects total), five years of sampling would be required to achieve greater than 80% power to detect a 25% change in the population of green sea urchins (power at n = five years is 97.8% ± 1.3% [95% CI]). In order to detect a 25% change over two years, the number of sites would need to increase to an unreasonably high number (Fig. 5a). However, if a larger effect size is acceptable (e.g., a 50% change in the population), approximately 17 sites would be adequate (Fig. 5b). The most appropriate approach for future monitoring will depend on the long-term monitoring objectives and species of interest. Power analyses should be rerun for specific species of interest to ensure that the monitoring program meets specific targets for effect size and power.

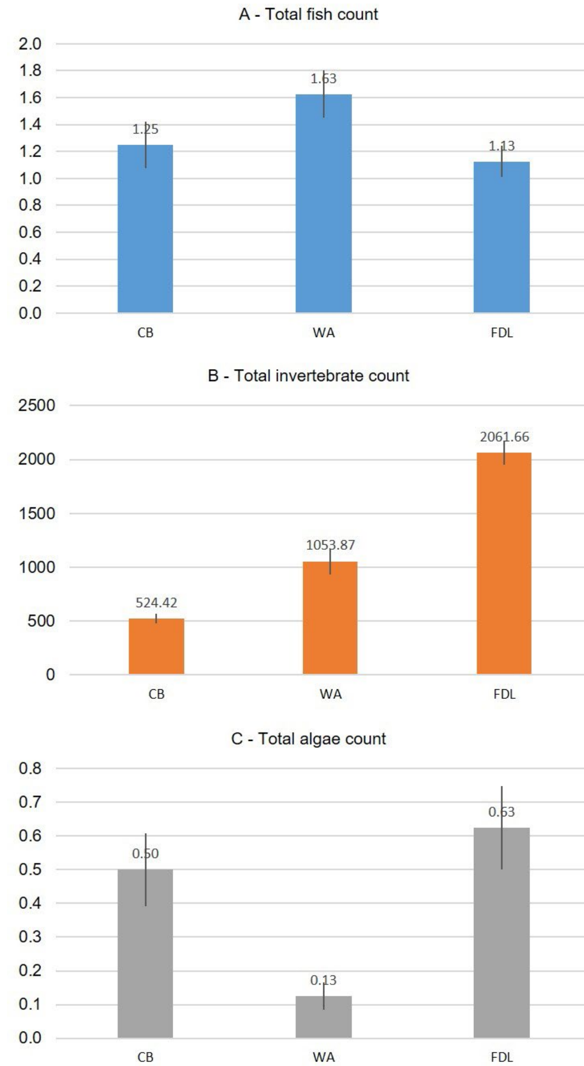


Figure 3: The mean abundance of (A) fish, (B) invertebrates, and (C) algae counted along 60 m2 transects in three areas near Cambridge Bay (CB = Cambridge Bay; WA = West Arm; FDL = Findlayson Islands). n = 8 transects in each area. Error bars represent standard error.

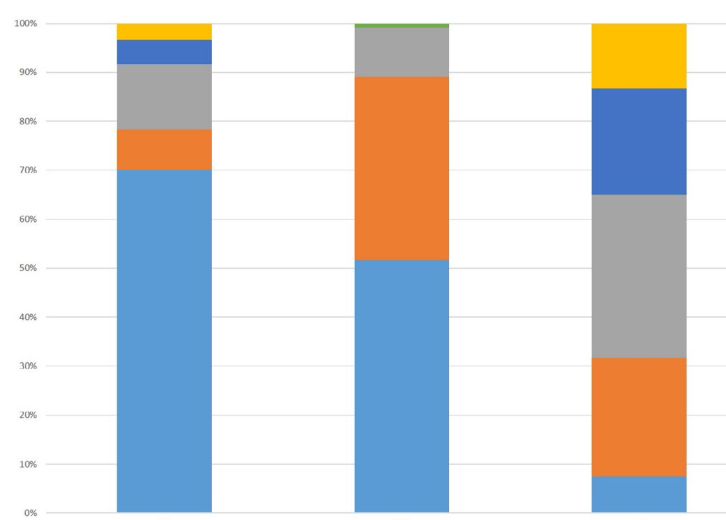


Figure 4: Proportion of substrate type for three areas near Cambridge Bay (CB = Cambridge Bay; WA = West Arm; FDL = Findlayson Islands). n = 8 surveys for each area.

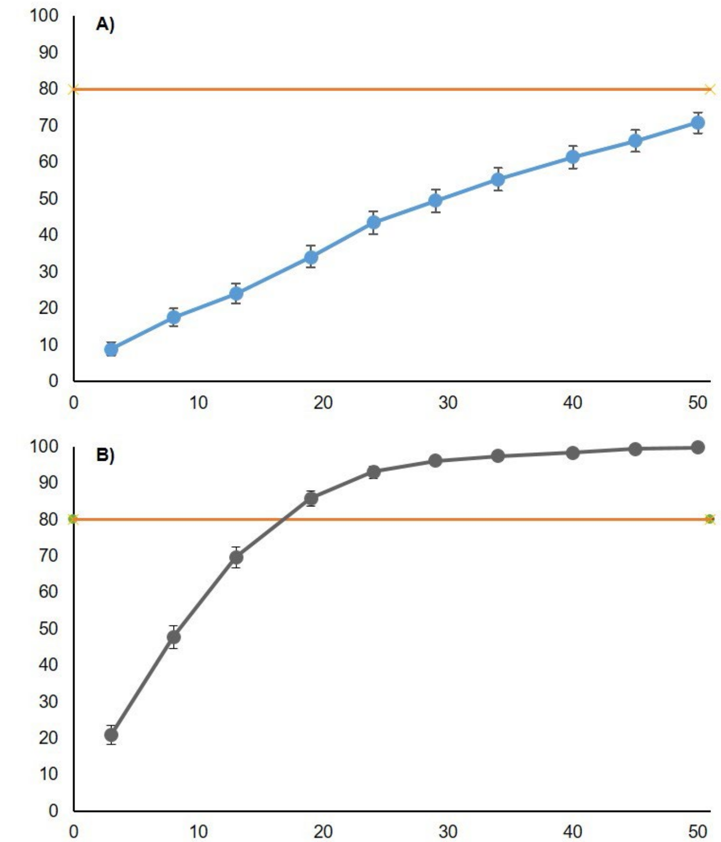


Figure 5: The estimated power to detect (a) a 25% change and (b) a 50% change in the population of green urchins for a given number of survey sites (with four transects per site) using a linear mixed-effects model (R "simr" package; Green and McLeod 2016). Horizontal dashed lines represent 80% power, which is a common target in ecological studies (Munkittrick et al. 2009).

Roving biodiversity surveys (taxon dives)

Eighteen roving biodiversity surveys (taxon dives) were undertaken, during which 161 species were noted (Fig. 6), including 20 not previously recorded during the 2015 or 2016 NES (2015 and 2016 NES final reports available on request). The observation of previously unobserved species suggests a need to continue this type of taxonomic work.

Comparison of transect and taxon dive methods

The species accumulation curve (Fig. 7) maintained an upward trajectory for roving biodiversity surveys, demonstrating that species richness would continue to climb with additional surveys, while the species accumulation using the transect method was, of course, maximized at the number of target species predetermined in the methods. On the other hand, the

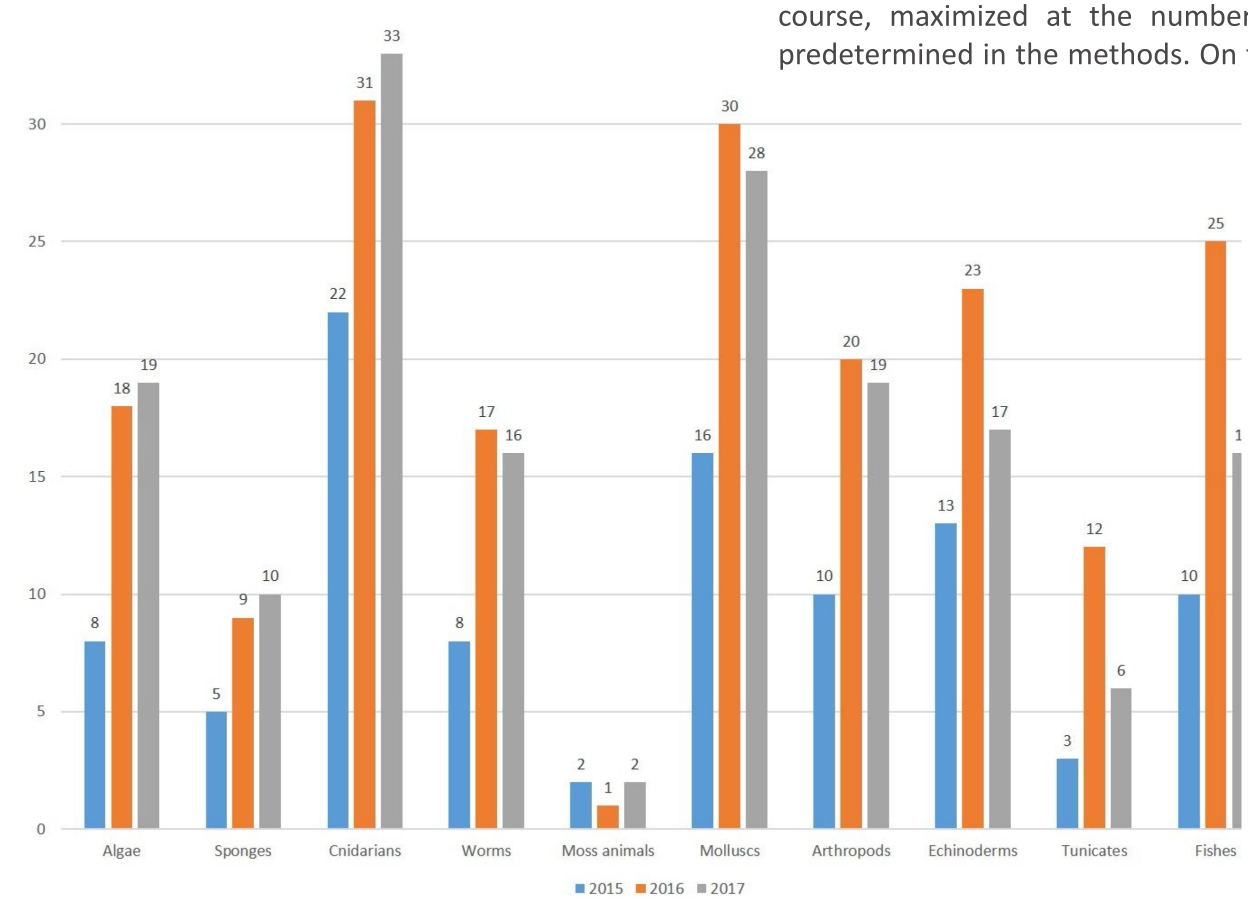


Figure 6: Comparison of number of species observed during the 2015 NES (6 dives), 2016 NES (14 dives), and 2017 AMEBP (18 dives).

transect method provides a more rigorous estimate of species abundance (Table 2) than the taxon method, which only approximates abundance and is therefore more subjective.

The most appropriate method for future monitoring will depend on the objectives of the program. Taxon dive surveys may be more appropriate if the objectives include capturing a greater breadth of biodiversity or detecting rare, endangered, or invasive species. However, if more repeatable and quantifiable data are required, the transect method may be more appropriate.

Next Steps

While traditional approaches to biodiversity research have made important strides in characterizing Arctic nearshore ecosystems, they have some limitations. For instance, because transect dives target specific species of interest and specific depths, they do not capture the

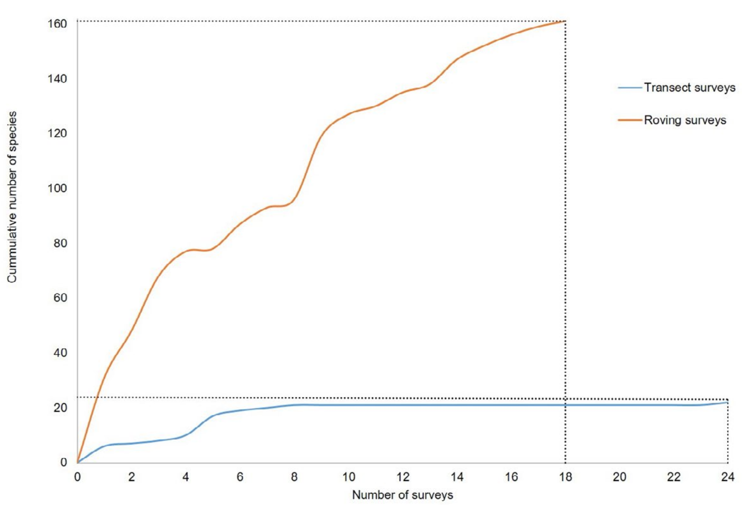


Figure 7: The cumulative number of taxa observed with each additional transect (solid blue line) or taxon dive survey (solid orange line). Surveys are in chronological order. Twenty-two taxa were observed after 24 transect dives, and 161 taxa were observed after 18 taxon dives.

full breadth of diversity at a given location. Likewise, taxonomic experts with experience scuba diving in the Arctic are rare, so precise species identification during a taxon dive can be challenging. One way to bolster traditional survey methods is to incorporate molecular methods such as DNA barcoding (Hebert et al. 2003). We recommend using the results of the 2017 AMEBP to adapt and continue transect surveys at select sites. However,

Figure 8: Children encounter live marine specimens at the community open house.

we also recommend augmenting and continuing roving biodiversity surveys and site exploration with DNA barcoding. In addition, we propose hosting a workshop with Cambridge Bay stakeholders to determine local priorities for future research.

Community Considerations

We strongly believe that increased awareness of the local underwater environment will lead to enhanced respect for its complexity and fragility, and serve to strengthen community support for ongoing monitoring efforts. To this end, the 2017 AMEBP included several hands-on community engagement events, including an open house for all Cambridge Bay residents and a program to introduce Kullik Ilihakvik Elementary School students to live specimens.

As well, we conducted a number of interviews with Cambridge Bay youth about environmental changes and the capacity of science and traditional knowledge to address the impact of climate change on the Arctic. The varied and thoughtful responses touched on concerns about food security, threats to animal populations, thinning ice, and invasive species. These interviews clearly indicated that future research projects must be structured to be relevant to Inuit concerns and priorities.

Acknowledgements

Polar Knowledge Canada and the Ocean Wise Conservation Association jointly provided funding for the 2017 Arctic Marine Ecology Benchmarking Program. We thank the residents of the hamlet of Cambridge Bay, John Lyall Jr., the POLAR CHARS team, Mia Otokiak, Candace Pedersen, the staff, teachers, and students at Kullik Ilihakvik Elementary School, the Ekaluktutiak Hunters and Trappers Organization, Kitnuna Corporation, Charlie Gibbs, and our colleagues at the Ocean Wise Vancouver Aquarium.

References

Chen, Y., and Hunter, M. 2003. Assessing the green sea urchin (*Strongylocentrotus drobachiensis*) stock in Maine, USA. *Fisheries Research* 60:527–537. doi:10.1016/S0165-7836(02)00082-6.

Coyer, J. A., Ambrose, R. F., Engle, J. M., and Carroll, J. C. 1993. Interactions between corals and algae on a temperate-zone rocky reef: Mediation by sea urchins. *Journal of Experimental Marine Biology and Ecology* 167:21–37.

Department of Fisheries and Oceans. 2013. Pacific region green sea urchin integrated fisheries management plan, September 1, 2013, to August 31, 2016.

Estes, J. A. and Duggins, D. O. 1995. Sea otters and kelp forests in Alaska: Generality and variation in a community ecological paradigm. *Ecological Monographs* 65 (1):75–100. doi:10.2307/2937159.

Green, P., MacLeod, C. J., and Nakagawa, S. 2016. SIMR: An R package for power analysis of generalized linear mixed models by simulation. *Methods in Ecology and Evolution* 7:493–498. doi:10.1111/2041-210X.12504.

Hebert, P. D. N., Cywinska, A., Ball, S. L., and deWaard, J. R. 2003. Biological identifications through DNA barcodes. *Proceedings of the Royal Society B: Biological Sciences* 270 (1512):313–321. doi:10.1098/rspb.2002.2218.

Marliave J. B., Gibbs, C. J., Gibbs, D. M., Lamb, A. O., and Young, S. F. J. 2011. Biodiversity stability of shallow marine benthos in the Strait of Georgia, British Columbia, Canada through climate regimes, overfishing, and ocean acidification. *In* Biodiversity loss in a changing planet. InTechOpen. pp. 49–74. Web ISBN: 978-953-307-707-9.

Munkittrick, K.R., Arens, C.J., Lowell, R.B., and Kaminski, G.P. 2009. A review of potential methods of determining critical effect size for designing environmental monitoring programs. Environmental *Toxicology and Chemistry* 28:1361–1371. doi:10.1897/08-376.1.

STRATIFICATION IN THE CANADIAN ARCTIC ARCHIPELAGO'S KITIKMEOT SEA:

Biological and geochemical consequences

William J. Williams[1 *], Kristina A. Brown[1], Bodil A. Bluhm[2], Eddy C. Carmack[1], Laura Dalman[4], Seth L. Danielson[3], Brent G. T. Else[5], Rosalyn Fredriksen[2], C. J. Mundy[4], Lina M. Rotermund[6], and Adrian Schimnowski[7]

[1] *Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, British Columbia, Canada*

[2] *Institute for Arctic and Marine Biology, UiT–The Arctic University of Norway, Tromsø, Norway*

[3] *College of Fisheries and Ocean Sciences, University of Alaska Fairbanks, Fairbanks, Alaska, United Sates of America*

[4] *Centre for Earth Observation Science, Department of Environment and Geography, University of Manitoba, Winnipeg, Manitoba, Canada*

[5] *Department of Geography, University of Calgary, Calgary, Alberta, Canada*

[6] *Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, Canada*

[7] *Arctic Research Foundation, 201 Bridgeland Avenue, Toronto, Ontario, Canada*

* *Bill.Williams@dfo-mpo.gc.ca*

The Kitikmeot Sea Science Study (K3S) is being led by Fisheries and Oceans Canada, in collaboration with the Arctic Research Foundation, UiT–the Arctic University of Norway, the University of Alaska Fairbanks, the University of Manitoba, the University of Calgary, and the University of Victoria. It is supported by Polar Knowledge Canada, the Arctic Research Foundation, Fisheries and Oceans Canada, and our collaborators. The study area comprises the Kitikmeot Sea: the entire marine region of the Kitikmeot between Dolphin and Union Strait in the west and Victoria Strait and James Ross Strait in the east.

Abstract

The Kitikmeot Sea Science Study was initiated in 2014 to provide the Canadian High Arctic Research Station a scientific basis for long-term ecological monitoring and research in the Kitikmeot Region of the southern Canadian Arctic Archipelago. The region is unique in the Arctic due to its shallow bounding sills and massive freshwater input relative to its area. Thus, three foci guide the study: (1) the Pacific-origin estuarine inflow, which sets the oceanographic structure; (2) the origin and pathways of fresh water, which influence nutrient balances and stratification; and (3) tidally influenced biological communities in narrow passages. To investigate these themes, we apply a suite of tools deployed from the R/V Martin Bergmann.

Our results show that the Kitikmeot Sea is characterized by two-layer estuarine flow, with surface outflows and subsurface inflows across the bounding sills. River inputs along the southern boundary deliver fresh water, terrestrial nutrients, and carbon to the riverine-coastal domain, which then spread throughout the system. Strong tidal currents in narrow passages enhance vertical heat and nutrient flux to maintain ice-free conditions in winter and tight pelagic-benthic coupling in summer. These narrow passages have hard bottom substrate inhabited by suspension feeders, while soft sediments with deposit feeders are found in areas of weaker currents elsewhere. Our analysis reveals a dynamic ecosystem characterized by pelagic-benthic coupling modified by the physical flow field and constrained by external inputs of nutrients and fresh water.

Suggested citation:

Williams, W.J., Brown, K.A., Bluhm, B.A., Carmack, E.C., Dalman, L., Danielson, S.L., Else, B.G.T., Fredriksen, R., Mundy, C.J., Rotermund, L.M., and Schimnowski, A. 2018. Stratification in the Canadian Arctic Archipelago's Kitikmeot Sea: Biological and geochemical consequences. Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 46–52. DOI: 10.35298/pkc.2018.06*

Introduction

The Kitikmeot Sea (Fig. 1) — which includes Coronation Gulf, Bathurst Inlet, Queen Maude Gulf, and Chantrey Inlet in the southern Canadian Arctic Archipelago — is unique in the pan-Arctic system due to (1) its massive freshwater input relative to the area's size, (2) its primary nutrient supply delivered from the Canada Basin, and (3) its shallow bounding sills to the west and northeast (≤ 30 m deep). These conditions maintain an estuarine-like circulation wherein surface outflowing fresh water of river and ice melt sources mixes with the deeper, salty oceanic waters that enter over the shallow bounding sills. Thus, strong salt stratification generally restricts vertical mixing and the upward fluxes of dissolved nutrients, resulting in overall relatively low primary production of the region. The resulting low annual biological production must affect the entire food web, and we speculate that this is a contributing factor to the lack of top predators, the larger polar bears and whales, that are found elsewhere.

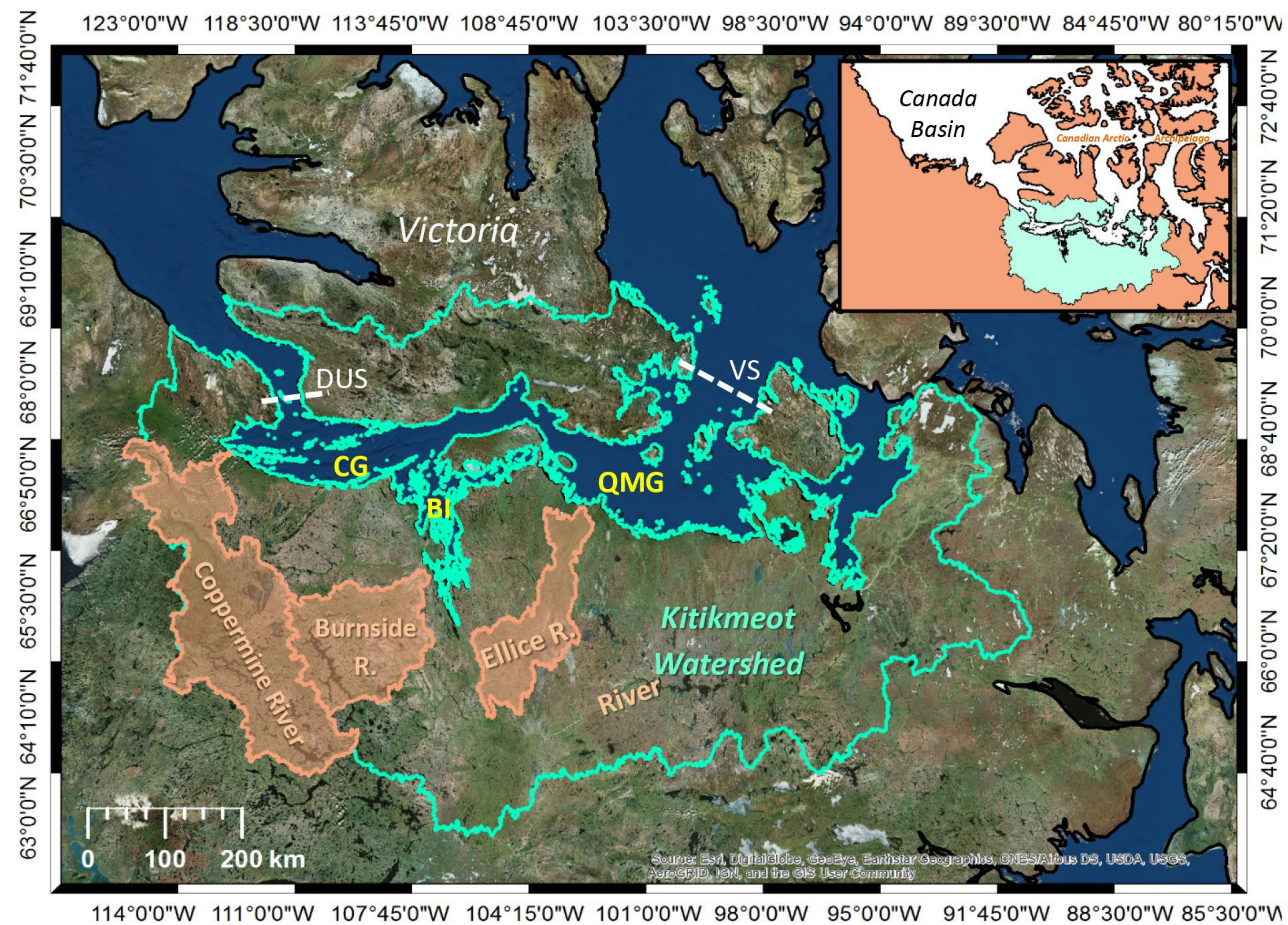


Figure 1: Kitikmeot Sea Region of the southern Canadian Arctic Archipelago. Inset plot shows the land area draining into the Kitikmeot Sea ("Kitikmeot Watershed"), shaded green in the context of the Canadian Arctic Archipelago (pink). Main plot shows the watersheds for the Coppermine, Burnside, and Ellice Rivers, shaded pink, that drain into Coronation Gulf (CG), Bathurst Inlet (BI), and Queen Maud Gulf (QMG) respectively. Shallow oceanic straits in both the west (Dolphin and Union Strait, DUS, 18 m sill) and northeast (Victoria Strait, VS, 20–30 m sill) restrict inflow of the relatively salty, nutrient-rich Pacific-origin waters that flow through the Canadian Arctic Archipelago. (From: Brown et al. 2016).

Low overall biological production compels us to look for specific locations where biological production might be enhanced. Observations by residents, combined with high-resolution satellite imagery, suggest that the narrow gaps and straits between the many islands of the Kitikmeot can be prone to early ice breakup, suggestive of thinner ice, which makes them dangerous places for winter travel (Fig. 2).

We hypothesize that these "winter holes" in the sea ice are caused by upward mixing of subsurface heat, induced as tidal flow accelerates over sills and through narrow passes (Fig. 2). Furthermore, as the subsurface water is likely relatively nutrient-rich, the same upward mixing will also deliver nutrients to the euphotic zone year-round. Therefore, we suggest that near these "winter holes" in sea ice there will be enhanced summertime biological productivity and a patchwork of enhanced benthic ecosystems. These "summer gardens," will contrast with the region's overall very low productivity (Fig. 3) and thus be biological hotspots may form critical feeding sites for the higher trophic levels.

The Kitikmeot Sea Science Study (K3S) was thus initiated in 2014 to investigate the hypothesis that *narrow gaps and straits between the many islands are year-round sites of vertical mixing, which results in polynyas in winter ("winter holes") and biological hotspots in summer ("summer gardens")*.

In addition, the K3S would provide the Canadian High Arctic Research Station a scientific basis for long-term ecological monitoring and research, and facilitate a strong partnership with CHARS. Three foci guide the study: (1) the Pacific-origin estuarine inflow, which sets the oceanographic structure; (2) the origin and pathways of fresh water, which influence nutrient balances and stratification; and (3) tidally influenced biological communities in narrow passages. We apply a suite of oceanographic tools and year-round moorings deployed from the *Martin Bergmann* to investigate these themes.

The K3S carried out observational field programs within the Kitikmeot Sea aboard the *Martin Bergmann* from 2014 to 2017, gathering a suite of new and exciting observations and advancing our understanding of this region (e.g., Williams et al. 2016, 2017; Brown et al. 2016; Rotermund et al. 2017; Fredriksen 2018). To be more inclusive of the entire region being investigated (terrestrial and marine), the Kitikmeot Marine Region Science Study (KMRSS) changed its name to the Kitikmeot Sea Science Study (K3S) during the 2017 program. The following report summarizes the main findings of the K3S field program carried out over the summers of 2014 to 2017.

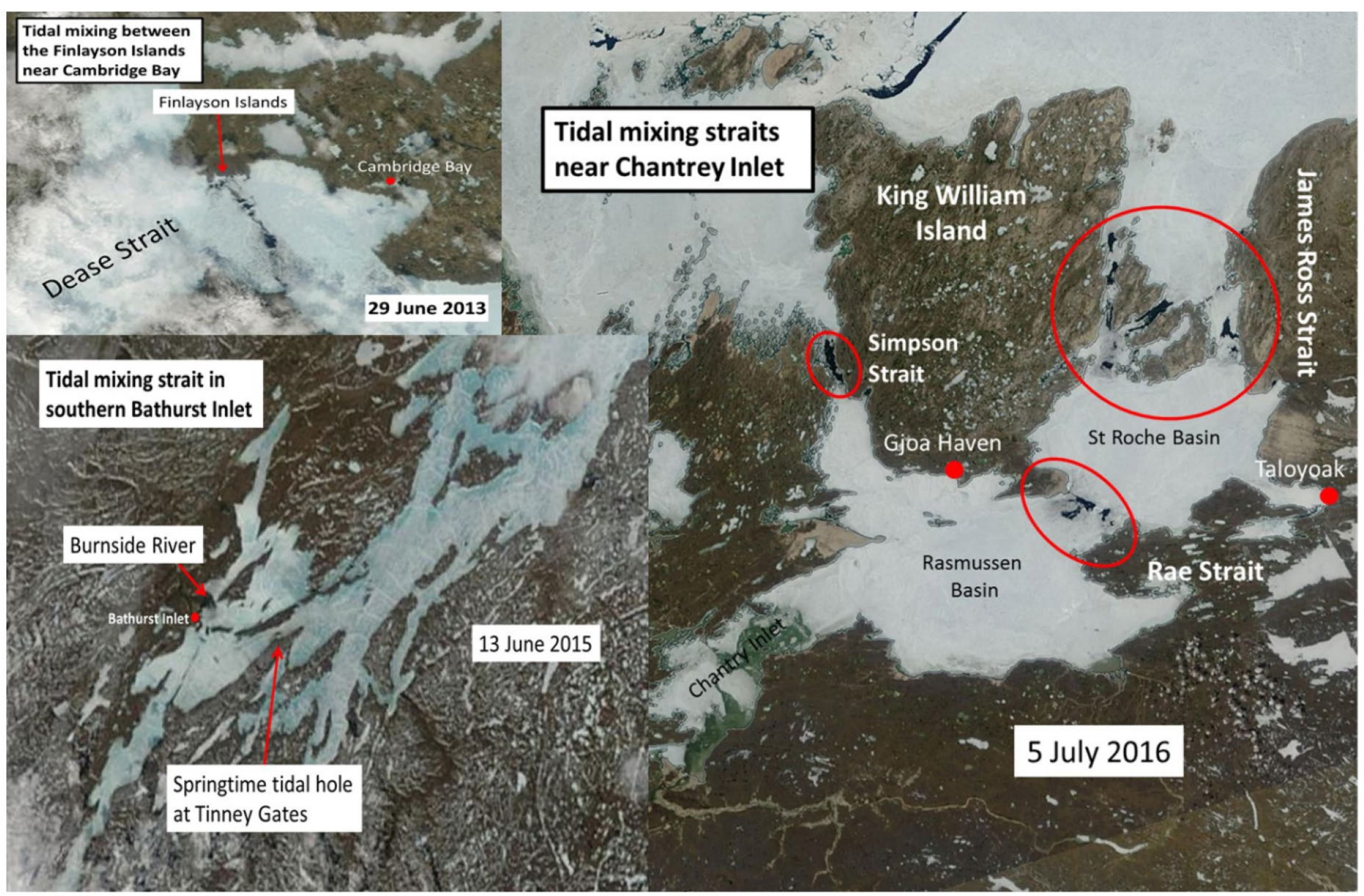


Figure 2: Satellite view of the springtime tidal mixing straits ("winter holes") in sea ice in the Finlayson Islands (upper left), Chantrey Inlet (right), and Bathurst Inlet (lower left). (From: Williams et al. 2016).

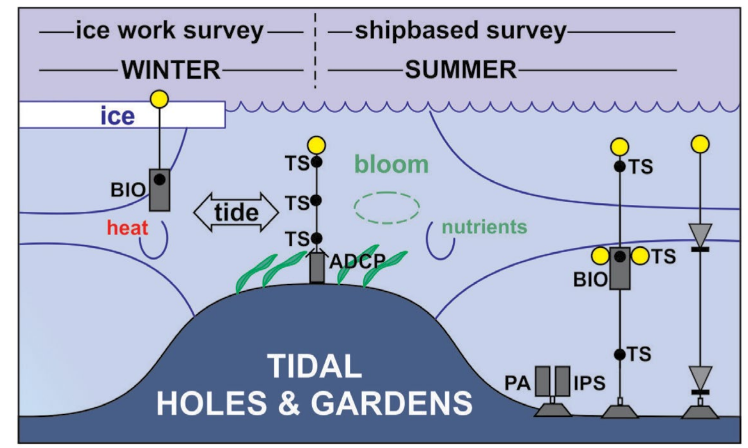


Figure 3: Schematic of the annual cycle of "tidal holes" and "gardens," showing the mechanisms by which tidally driven "winter holes" in sea ice may lead to high local biological production during the growing season ("summer gardens'). Contours represent isopycnal lines denoting stratification. Moored instrumentation measures the seasonal variation in temperature and salinity stratification (TS), profiles ocean currents (Acoustic Doppler Current Profiler, ADCP), assesses the biological response to light (Bio-optical package, BIO), listens for marine mammals (Passive Acoustics, PA), and measures ice draft (Ice Profiling Sonar, IPS). (By: Eddy Carmack, From: Williams et al. 2016).

Estuarine circulation and Pacific water through-flow

One of the main foci of the K3S is the investigation of the Pacific-origin inflow, which sets the oceanographic structure of the region. The sub-surface, Pacific-origin water flows from the Canada Basin through the Canadian Arctic Archipelago and is restricted from entering the Kitikmeot Sea due to the shallow oceanic straits in both the west (Dolphin and Union Strait, DUS, 18 m sill) and northeast (Victoria Strait, VS, 20–30 m sill) (Fig. 1; e.g., McLaughlin et al. 2006; Michel et al. 2015). The subsurface waters that make it into the Kitikmeot Sea across these shallow sills are the upper layers of the Pacific-origin water and are relatively salty and nutrient-rich. These Pacific inflows (Salinity = 29, Volume ≈ 256 km3 yr-1) are expected to combine with the river inputs to the Kitikmeot Sea (Salinity = 0, Volume of river inputs ≈ 41 km3 yr-1; Williams et al. 2016) and low-salinity sea ice melt to form the shallow surface outflow from the Kitikmeot Sea (Salinity ≈ 25, Volume ≈ 297 km3 yr-1). This describes an estuarine-like circulation in which inflowing river water mixes with the deep inflowing salty oceanic waters to produce the low-salinity surface outflow, and yields a residence time of about 13 years for waters residing in the Kitikmeot Sea (Williams et al. 2016).

The origin and pathways of the Kitikmeot Sea's freshwater components (precipitation, river input, and sea ice melt) influence nutrient balances and stratification in the surface ocean. River inputs alone account for as much as 70 cm of fresh water added annually to the surface of the Kitikmeot Sea (Brown et al. 2016), and can be a seasonal source of terrestrial nutrients (nitrate and silicate) for the coastal marine system, providing the necessary nutrients for primary producers once mixed with deeper Pacific-origin waters, which supply ample phosphate. The confluence of terrestrial nitrate and marine phosphate in the estuaries of the Kitikmeot Sea could play an important role contributing to the productivity of the coastal region (Brown et al. 2016). For example, nutrient relationships in Coronation Gulf and Queen Maud Gulf show lower nitrate and phosphate (but similar nitrate:phosphate ratios) compared with the same depths in Amundsen Gulf and Larsen Sound, but much higher silicate (Fig. 4; Williams et al. 2017).

Evidence of mixing in tidal straits

Stratification from fresh water in the surface ocean restricts the mixing of deep Pacific-origin nutrients into the photic zone, where it could fuel primary production. The tidal flows in numerous narrow straits of the Kitikmeot Sea provide opportunities to mix deep nutrients up to the surface, breaking this strong surface stratification. Tidal currents are highest in narrow straits, and should contribute to mixing throughout the year, generating the open-water "winter holes" in springtime ice (Fig. 2). During the 2017 field season, we deployed rapid-sampling moorings to obtain a time series of temperature, salinity, and chlorophyll fluorescence data over a 24-hour period to observe the tidal cycle. Figure 5a illustrates observations from just south of the narrow strait at Tinney Gates in southern Bathurst Inlet (Fig. 2). Here, both slow and rapid fluctuations in salinity are observed at the three different depth intervals. These vertical isopycnal displacements and diapycal mixing both have potential to deliver nutrients from deeper Pacific-sourced waters into the photic zone at regular intervals. Further observations of tidal mixing were observed in Unahitak Narrows, a narrow strait between the Finlayson Islands in Dease Strait near Cambridge Bay (Fig. 5b, 5c; Rotermund et al. 2017). Here, repeat Underway-CTD sections illustrate that as the tidal cycle progresses to peak flow, isohalines (e.g., S = 27 g kg-^{1}) are brought towards the surface by the tides over the Unahitak Narrows sill, again with the potential of bringing deeper nutrients into the photic zone.

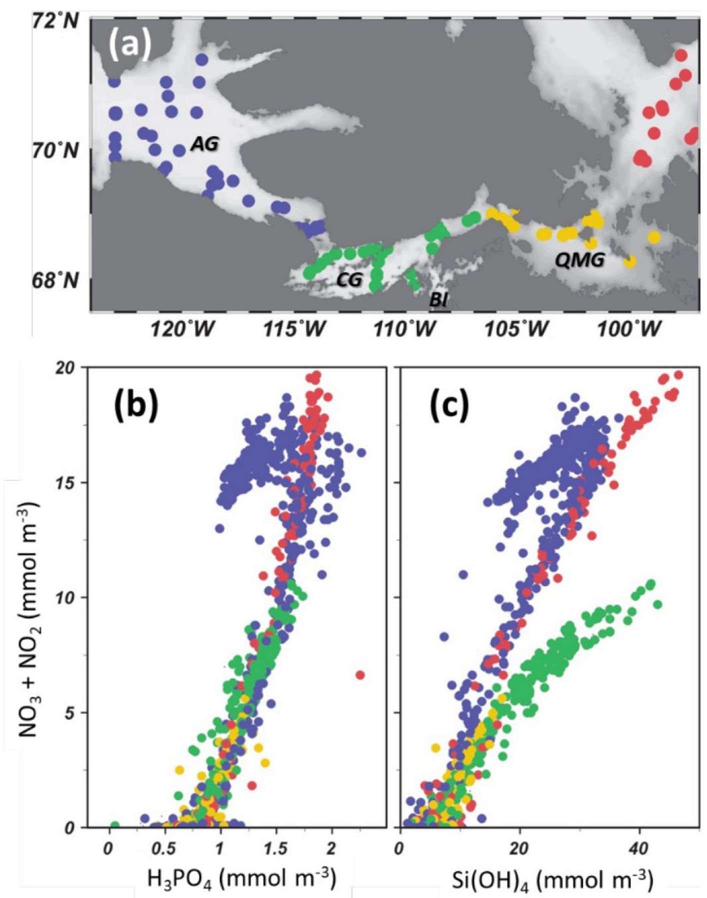


Figure 4: Nutrient relationships in Coronation Gulf (CG) and Queen Maud Gulf (QMG) show lower nitrate and phosphate (but similar nitrate/phosphate ratios) compared with the same depths in Amundsen Gulf (AG) and Larsen Sound (LS), but much higher silicate.

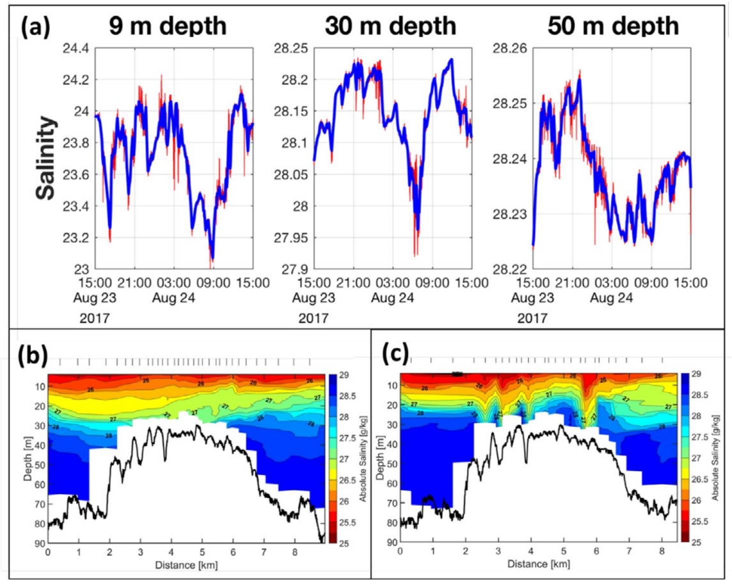


Figure 5: (a) Deployments of rapidly sampling moorings from just south of the narrow strait at Tinney Gates on Aug 23 to 24, 2017, show both slow and rapid fluctuations in salinity over 24 hrs and (b) and (c) Repeat Underway-CTD sections through the Finlayson Islands on Aug 18, 2017, (b) at 09:00 GMT and (c) 9 hrs later at 18:00 GMT. These show that as the tidal cycle progresses to peak flow, isohalines (e.g., S = 27 g kg-1) are brought towards the surface due to tidal mixing over the sill.

Increased ice algae in "winter holes" and differing benthic structure in "summer gardens"

Mixing of deep Pacific-origin nutrients up to the photic zone within the Kitikmeot Sea tidal straits creates favourable conditions for primary producers, with cascading effects into the food web. Examples of this can be found in both winter and summer studies investigating the "holes" and "gardens" potentially created by these tidal straits. Winter studies in the Finlayson Islands from 2016 indicate that ice algal biomass and current velocity were highest in the centre of the tidal straits, and decreased moving away from the straits towards the west (Fig. 6a; Dalman et al. 2017). Summertime observations of benthic communities indicate that high-flow sites, low-flow sites, and transitional sites differed in community composition (Fig. 6b; Fredriksen 2018). Suspension feeders (e.g., sea cucumbers, cnidarians, and feather stars) dominated sites with high-current velocities in the tidal straits whereas surface-deposit feeders (e.g., brittle stars) dominated in low-flow areas downstream (Fig. 6b; Fredriksen 2018). Stable isotope data reveals further information on the food web structure and indicates tight coupling of benthos to phytoplankton-based food sources both in the tidal straits and just downstream from them (Fredriksen 2018). As well, grazers and suspension feeders in the tidal straits appear to use the freshest material, whereas surface-deposit feeders in downstream areas that accumulate sediment are slightly more isotopically enriched (Fredriksen 2018).

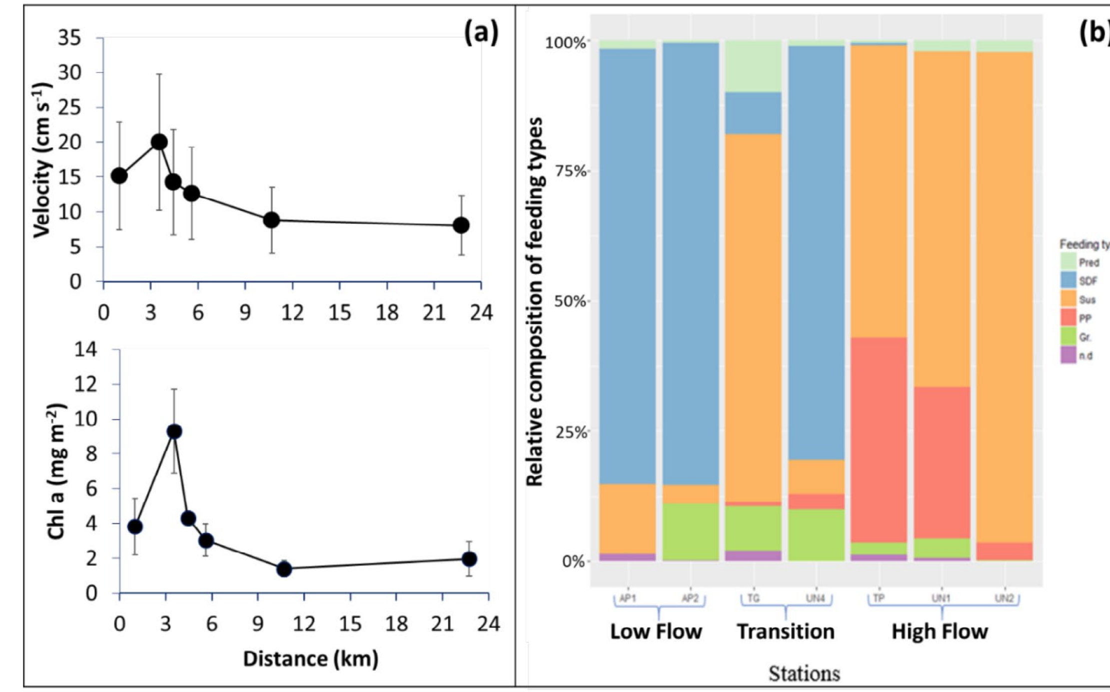


Figure 6: (a) At the Finlayson Islands, ice algal biomass (chlorophyll a, bottom) and current velocity (top) were highest in the centre of the tidal straits(at 3 km in the transect) and decreased moving east and (b) Benthic communities of suspension feeders (Sus, e.g., sea cucumbers, cnidarians, and feather stars) dominated sites with high-current velocities in the tidal straits, and surface-deposit feeders (SDF, mostly brittle stars) dominated in low-flow areas downstream (pred = predator/scavengers, PP = primary producer, Gr. = grazers, n.d = not defined).

Conclusions

Preliminary observations from the K3S illustrate the unique nature of the Kitikmeot Sea. Pacific-origin waters combined with freshwater input from the large terrestrial drainage basin set up the estuarine structure of the Kitikmeot Sea and further influence both its nutrient balance and stratification. Mixing within tidal straits works to break this stratification and bring Pacific nutrients into the photic zone, where they are available to primary producers. Observations of under-ice and benthic communities illustrate the effects of these physical processes on the food web, showing increased concentrations of ice algae within tidal straits and a shift in benthic communities towards suspension feeders, which can capitalize on sinking material associated with enhanced surface ocean productivity. The K3S will continue to investigate these themes in collaboration with community partners throughout the Kitikmeot region through 2018 and beyond.

Community considerations

Our oceanographic exploration of the Kitikmeot Sea aims to provide a description of the functioning and connectivity of the marine ecosystem that complements indigenous knowledge and is useful to northern communities. These communities depend on the marine food web for fish and seals, and on the sea ice for travel. Our results are beginning to provide a scientific basis for higher biological production and dangerous thin ice in the tidal straits of the region. Our development of the 'winter-holes-and-summer-gardens' model is based on our general understanding of coastal oceans and conversations with Canadian Rangers as part of the wintertime Canadian Rangers Ocean Watch program. We also conduct and encourage training and capacity building for oceanographic monitoring in the region via Canadian Rangers Ocean Watch, in collaboration with Ocean Networks Canada and the Arctic Research Foundation. Community-based oceanographic time series initiated in the Kitikmeot can be placed in context using the oceanographic understanding developed by the K3S.

Acknowledgements

We would like to thank the captains and crew of the *Martin Bergmann*. Their skill and flexibility allow complex interdisciplinary oceanographic expeditions to be conducted from their small ship; without their support, the Kitikmeot Sea Science Study would not be possible. Also, this oceanographic research is only possible with the vision and support of Jim Balsillie, the founder and benefactor of the Arctic Research Foundation, which owns the Martin Bergmann research vessel. We also acknowledge the Nunavut Planning Commission, the Nunavut Impact Review Board, and the Nunavut Research Institute for granting permission for this research to be conducted in their territorial waters.

References

Brown, K., Williams, W., Carmack, E., Schimnowski, A., Nivingalok, J., and Clarke, C. 2016. Where the river meets the sea: Investigating nutrient dynamics in the Kitikmeot riverine-coastal domain. ArcticNet Annual Scientific Meeting, Winnipeg, Man., December 2016. [poster presentation].

Dalman, L., Else, B., Barber, D., Carmack, E., Williams, W.J., Campbell, K., and Mundy, C.J. 2017. Tidal straits as hotspots for ice algal production: A case study in the Kitikmeot Sea. International Arctic Change Conference, Québec, P.Q., 11–15 December. [poster presentation].

Fredriksen, R. 2018. Epibenthic community structure in northeast Greenland and the Kitikmeot Sea in the Canadian Arctic Archipelago. M.Sc. thesis, Faculty of Biosciences, Fisheries, and Economics, Department of Arctic and Marine Biology, Institute for Arctic and Marine Biology, UiT–The Arctic University of Norway, Tromsø, Norway.

McLaughlin, F.A., Carmack, E.C., Ingram, R.G., Williams, W., and Michel, C. 2006. Oceanography of the Northwest Passage. In The sea, vol. 14B, chap. 31, Robinson, A. and Brink K. (eds.), Harvard Press. pp. 1213–1244.

Michel, C. et al. 2015. Arctic Ocean outflow shelves in the changing Arctic: A review and perspectives. Progress In Oceanography. Available from http://dx.doi.org/10.1016/j.pocean.2015.08.007.

Rotermund, L. M., Williams, W.J., Brown, K.A., Danielson, S.L., Carmack, E.C., Bluhm, B.A., and Klymak, J.M. 2017. Tidal mixing and advection in Dease Strait: The connection between Coronation Gulf and Queen Maud Gulf. Arctic Change, Québec, P.Q., 11–15 December 2017. [poster presentation].

Williams, W., Bluhm, B., Brown, K. Carmack, E., Danielson S., Mundy C.J., and Rotermund L. 2017. Making and breaking stratification in the Canadian Arctic Archipelago's Kitikmeot Sea: Biological and geochemical consequences. Arctic Change, Québec, P.Q., 11–15 December 2017. [poster presentation].

Williams, W., Bluhm, B., Brown, K., Carmack, E., Clarke, C., Danielson, S., Rotermund, L.M., Schimnowski, A., and Schimnowski, O. 2016. Adventures in a new Arctic frontier: Investigating the tidal-driven "winter holes" and "summer gardens" of the Kitikmeot Marine Region of the Canadian Arctic Archipelago. ArcticNet Annual Scientific Meeting, Winnipeg, Man., December 2016. [oral presentation].

PUSHING REMOTE SENSING CAPACITY FOR CLIMATE CHANGE RESEARCH IN CANADA'S NORTH:

POLAR's contributions to NASA's Arctic-Boreal Vulnerability Experiment

Adam Houben[1*], Donald McLennan[1], Scott Goetz[2], Charles E. Miller[3], Peter Griffith[4], Elizabeth Hoy[4], and Elisabeth Larson[4]

[1] *Science and Technology, Polar Knowledge Canada, Cambridge Bay, Nunavut, Canada*

[2] *School of Informatics, Computing, and Cyber Systems, Northern Arizona University, Flagstaff, Arizona, United Sates of America*

[3] *NASA Jet Propulsion Laboratory, Pasadena, California, United Sates of America*

[4] *NASA Goddard Space Flight Center, Greenbelt, Maryland, United States of America*

* *adam.houben@polar.gc.ca*

Abstract

NASA's Arctic-Boreal Vulnerability Experiment (ABoVE) is a ten-year study of ecosystem response to environmental change across Alaska and northwestern Canada, utilizing and testing space-based and airborne remote sensing technologies. Consultations at the planning stages of the project included a concerted push by Polar Knowledge Canada (POLAR) to extend the domain to High Arctic landscapes. POLAR now participates with NASA in the ABoVE Coordinating Group, aiding in the coordination of Canadian research, data management, and the acquisition of RADARSAT-2 satellite imagery with the Canadian Space Agency (CSA). POLAR is also leading ecosystem studies at the Canadian High Arctic Research Station (CHARS) campus, one of the few High Arctic sites within the study domain. POLAR also funds several projects associated with the ABoVE program, across several of the thematic working groups.

The first ABoVE Airborne Campaign (AAC) finished in 2017, with remote sensing instruments measuring a diverse suite of environmental variables. These technologies were intended to align with field researchers for ground calibration and validation. At the CHARS study site, both the AVIRIS-ng and ASCENDS jet-based instrumentation suites surveyed the Greiner watershed component of the CHARS Experimental and Reference Area (ERA) for vegetation and CO_2 respectively.

ABoVE education activities have also been coordinated in northern communities. The Earth to Sky course held in Yellowknife in April 2017 brought US and Canadian scientists together with educators and representatives of First Nations to share in how they observe, understand, and interpret environmental change. Then, during the airborne campaign in May and August of 2017, NASA and the Government of the Northwest Territories (GNWT) organized open houses at the Yellowknife airport, where youth and the public were able to see several of the jets and sensors, and receive an overview of ecosystem and remote sensing sciences.

Suggested citation:

Houben, A., McLennan, D., Goetz, S., Miller, C.E., Griffith, P., Hoy, E., and Larson, E. 2018. Pushing remote sensing capacity for climate change research in Canada's North: POLAR's contributions to NASA's Arctic-Boreal Vulnerability Experiment (ABoVE). Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 53–62. DOI: 10.35298/pkc.2018.07*

Introduction and ABoVE overview

Polar Knowledge Canada (POLAR) is developing a strong research presence in the Arctic, based out of the Canadian High Arctic Research Station (CHARS) campus in Cambridge Bay, Nunavut, to serve Canada and the world. Its mission is to advance knowledge of the Arctic in order to improve economic opportunities, environmental stewardship, and quality of life for northerners and all Canadians. One of the ways that this mission will be achieved is through strengthening of monitoring activities designed to provide important baseline environmental information, as well as sponsoring research to fill critical knowledge gaps.

NASA is implementing the Arctic-Boreal Vulnerability Experiment (ABoVE), a large-scale study of ecosystem responses to environmental change in the Arctic and boreal regions of northwestern North America (Fig. 1) and the implications for social-ecological systems (above.nasa.gov). ABoVE's science objectives focus on (1) developing a fuller understanding of the vulnerability and resilience of Arctic and boreal ecosystems to environmental change in western North America, and (2) providing the scientific basis for informed decision-making to guide societal responses from local to international levels.

There is significant overlap between the scientific objectives and geographic domains for POLAR and ABoVE; the geographic domains include much of Yukon, the Northwest Territories, and Nunavut in northwestern Canada, encompassing boreal and tundra landscapes. In addition, both POLAR and ABoVE will focus on the monitoring and research needed to understand how terrestrial and freshwater ecosystems and permafrost are responding to environmental change, and how these responses alter the ecosystem services that are provided to society within and beyond this region. The research and monitoring activities carried out through POLAR and ABoVE will include the collection, synthesis, and analyses of in situ and remote sensing data, and the use of models to effectively integrate and extrapolate observational data to describe large-area processes and to communicate information required by decision makers and stakeholders. These common areas of interest provide the foundation for collaborations between POLAR and ABoVE in pursuing their common goals.

Ecosystem change is rapidly occurring across Canada's North because of climate change — from the northward movement of treeline to permafrost degradation and thermokarst expansion, from increased forest fire events and burn severity to accelerating greenhouse gas emissions. Observing these changes across the remote and challenging environments of the North is inherently difficult. Thus, utilizing remote sensing is pivotal to monitoring northern environmental, social, and economic sustainability. This includes novel airborne sensors and orbiting satellites, with concurrent

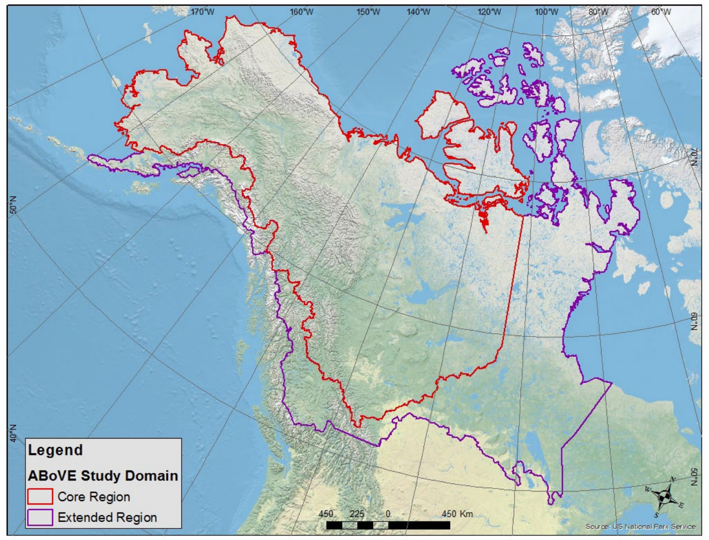


Figure 1: The ABoVE study domain includes Arctic and boreal terrestrial landscapes in Alaska and much of western Canada. The core region of the study domain captures the regional-scale variations in surface and atmospheric conditions, necessary to address the science questions and objectives. It includes landscapes and ecoregions that are rapidly changing in complex ways, as well as others that are not — a combination that allows for studies on both vulnerability and resilience. The study domain includes an extended region outside of the core region, which allows for studies focused on a subset of important changes that are not occurring in the core region (e.g., insect outbreaks and forest dieback in the southern boreal forest). The extended region includes areas where research focuses on environmental conditions that are considered to be antecedent to those in the core region. Studies conducted in the extended region also provide opportunities for collaboration with existing or planned research.

calibration and validation by field researchers on the ground, to answer some of these climate change questions over a ten-year period and beyond.

This paper also describes the partnership with POLAR during the program planning stage. Following that, a description of the first ABoVE Airborne Campaign (2017) outlines the airborne assets, instrumentation, and flight paths taken over the ABoVE domain. A brief summary of POLAR-supported ABoVE projects and field of study is then provided. In conjunction with NASA's airborne fleet, POLAR is also coordinating with the Canadian Space Agency in the tasking and acquisition of RADARSAT-2 imagery over several years to further support instrumentation and field studies. This may lead to additional support from the Polar Space Task Group in subsequent years. Finally, on top of the large-scale scientific focus of ABoVE, a summary of parallel education and outreach activities and community considerations are described, as well as the future phases of ABoVE.

NASA-POLAR consultations at the ABoVE planning stages

Given POLAR's role and jurisdiction for the Canadian Arctic, a POLAR representative joined the NASA ABoVE Science Definition Team while the project was being scoped and designed, at the request of Environment Canada. With an additional representative from the Canadian Forest Service, this was the Canadian component of the ABoVE team that contributed to the development of the NASA ABoVE Concise Experiment Plan (available from https://above.nasa.gov/acep.html) that defined the geographic scope of the project, confirmed project goals, and identified key questions the project would address. Another key development was the generation of a Memorandum of Understanding (MoU) between NASA and POLAR that outlined the roles and responsibilities of the two parties in implementing the ABoVE project in Canada. In this MoU, POLAR's roles included the coordination of work and liaison with communities and governments within the joint study area in Canada, ensuring that airborne operations comply with Government of Canada aircraft operating regulations, providing for the coordination of ground observations in Canada, defining data management approaches, and providing funds as possible to Canadian researchers to complement the NASA funding. The MoU was advanced in preparation for the White House Ministerial Meeting in September 2016, where the NASA-POLAR relationship was included as an example of positive US-Canada science cooperation in the North.

2017 ABoVE Airborne Campaign

The 2017 ABoVE Airborne Campaign (AAC) was one of the largest, most complex airborne science experiments conducted by NASA's Earth Science Division. Between April and November, the AAC involved ten aircraft in more than 200 science flights that conducted surveys across more than 4 million km2 in Alaska and northwestern Canada. Many flights were coordinated with same-day ground-based measurements to link process-level studies with geospatial data products derived from satellite sensors. The AAC collected data spanning the critical intermediate space and time scales that are essential for a comprehensive understanding of scaling across the ABoVE study domain, and ultimately extrapolation to the pan-Arctic, using satellite data and ecosystem models. The AAC provided unique opportunities to validate satellite and airborne remote sensing data and data products for northern high-latitude ecosystems. The science strategy coupled domain-wide sampling with instruments commonly known as "foundational instruments," L-band and P-band synthetic aperture radar (SAR), imaging spectroscopy, full waveform Light Detection and Ranging (LIDAR), and measurements of atmospheric trace gases (including carbon dioxide and methane), as well as PI-led studies using Ka-band SAR and solar-induced chlorophyll fluorescence. Targets of interest included field sites operated by the ABoVE Science Team as well as the intensive and/or long-term sites operated by US and Canadian partners. An example of an airborne instrument configuration is given in Figure 2 — an Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) unit.

One component of the 2017 airborne campaign surveyed the CHARS campus and Cambridge Bay area (Fig. 3). This included the Active Sensing of CO2 Emissions over Nights, Days, and Seasons (ASCENDS) suite of instrumentation onboard NASA's DC-8 aircraft and the Airborne Visible/Infrared Imaging Spectrometer-Next Generation (AVIRIS-ng) onboard an A200 aircraft. A summary of the ABoVE sensors/instruments, what they were used to measure, and platforms used to collect the data is provided in Table 1. One set of flightlines within the CHARS Experimental and Reference Area (ERA) showing data acquisitions from the NASA AVIRIS-ng hyperspectral sensor is shown in Figure 4.

NASA is planning to return to Canada and Alaska in 2018 with two of the instruments deployed in the 2017 airborne campaign. The notional plan as of this writing is to conduct AVIRIS-ng flights in midsummer 2018 and 2019, and L-Band SAR flights in late August of 2018 and 2019. AVIRIS-ng is tentatively scheduled to fly sites around Fairbanks and Barrow, Alaska; the Old Crow Flats, Yukon; and the Mackenzie Delta, Northwest Territories. L-Band SAR will be repeating lines flown during the 2017 campaign, with the objective of establishing multiyear time series for ABoVE science investigations, and is tentatively scheduled to fly the Boreal Ecosystem Research and Monitoring Sites (BERMS) in Saskatchewan, road-accessible sites near Yellowknife, Whitehorse, Kluane Lake, and Inuvik, and a subset of sites in Alaska that are of greatest interest to the SAR Working Group. Notional flightlines, subject to modification, will be posted as this planning progresses (available from https://above.nasa.gov/airborne_2017.html).

ABoVE projects and activities led or supported by POLAR

Roughly one quarter of the ~600 researchers in ABoVE are from Canadian organizations. Research is functionally guided by working groups focused on scientific fields that include hydrology and permafrost, vegetation dynamics, fire disturbance, carbon dynamics, wildlife and ecosystem services, modelling, and airborne science. POLAR hosts one of the High Arctic study sites in the CHARS ERA, staged from the CHARS campus (69.121119°N, -105.042189°W), with ecosystem studies scaling from submetre plots to local watershed mapping to the Kitikmeot region level for monitoring. In August 2017, the CHARS campus and town of Cambridge Bay witnessed the first ABoVE airborne campaign's arrival to measure atmospheric carbon dioxide emissions, as well as AVIRIS-ng hyperspectral imaging to assess vegetation characteristics.

Several POLAR researchers are also directly involved with the ABoVE program, and POLAR supports research projects through its grants and contributions program (Fig. 5). The first ABoVE-specific category was created

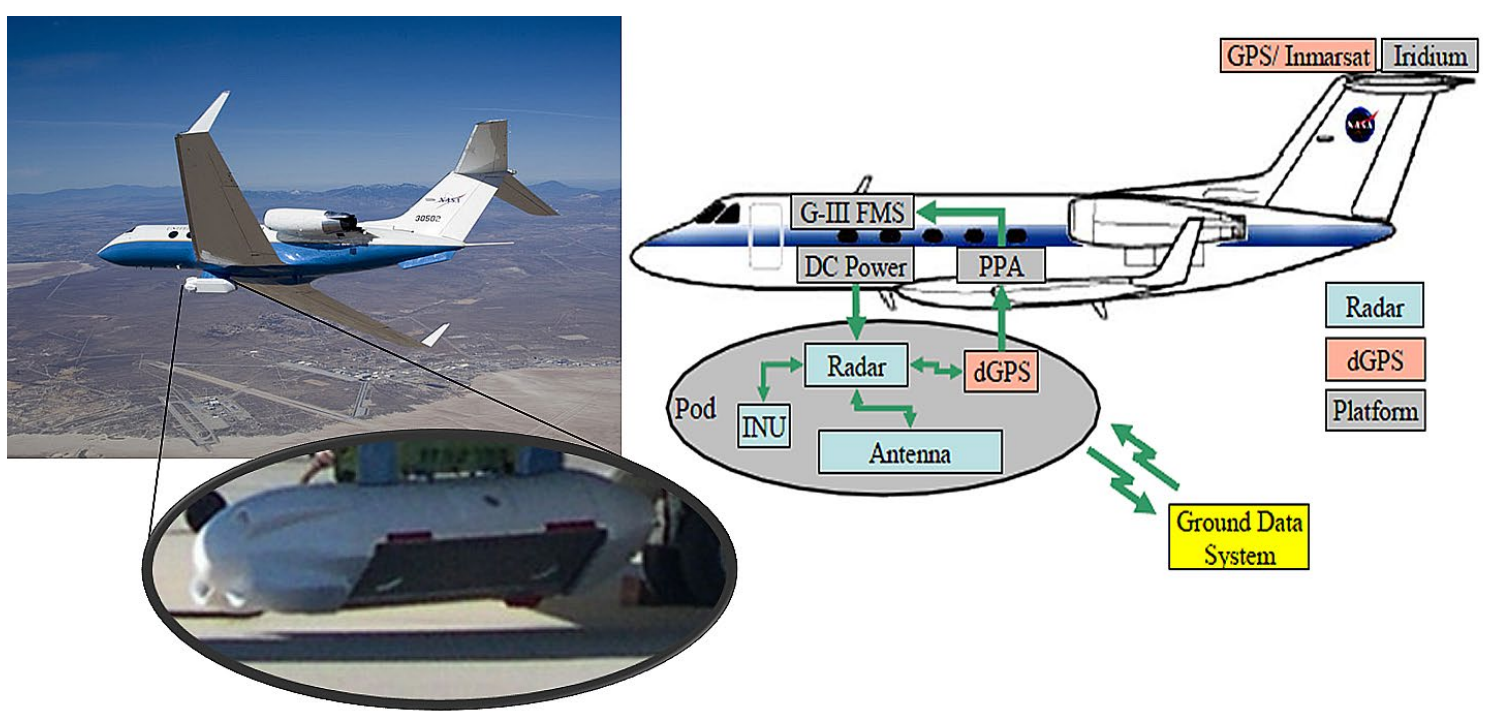


Figure 2: Photos and diagrammatic views of an airborne instrument, the UAVSAR in this example (Lee et al 2007).

Table 1: Instrumentation and aircraft utilized in the 2017 ABoVE Airborne Campaign.

Instrument	Description	Instrument Class	Measures	Aircraft
AirMOSS	Airborne Microwave Observatory of Subcanopy and Subsurface	P-band SAR	Repeated flights measure deformations in land, ice, soil moisture	G-III
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar	L/P-band SAR	Repeated flights measure deformations in land, ice, soil moisture imagery	C-20A
AirSWOT	Airborne Surface Water and Ocean Topography	Radar (KaSPAR)	Surface water and ocean topography	B200
ASCENDS	Active Sensing of CO_2 Emissions over Nights, Days, and Seasons	CO_2 sounder suite	Gases (carbon): shifts in terrestrial carbon sources/sinks	DC-8
ATM-C	Atmospheric Carbon	CO_2, CH4, CO	Gases (carbon)	Mooney
AVIRIS (NG)	Airborne Visible/ Infrared Imaging Spectrometer (Next Generation)	Spectrometer	Vegetation & atmosphere imagery: high signal:noise imaging in solar reflected spectral range	B200
CFIS	Chlorophyll Fluorescence Imaging Spectrometer	Spectrometer	Vegetation: solar-induced fluorescence	DHC6
LVIS	Land, Vegetation and Ice Sensor	Lidar	Surface topography and vegetation coverage	B200T

Figure 3: Productive lakes are visible on the landscape surrounding Cambridge Bay, Nunavut via AVIRIS-ng imagery, Aug. 2, 2017.

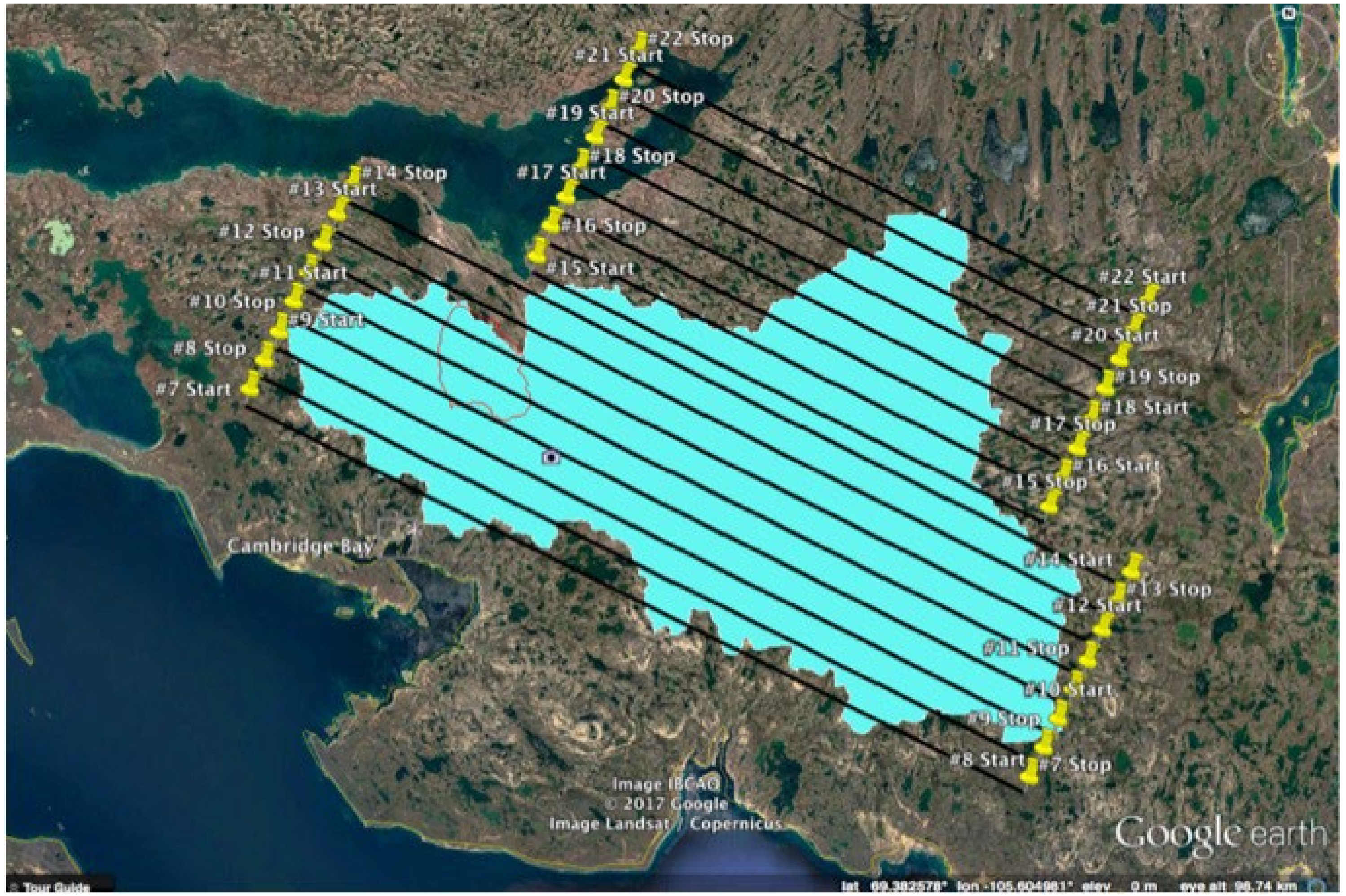


Figure 4: One set of 2017 AVIRIS-ng flightlines (in black) over the CHARS ERA and Greiner watershed (aqua fill colour).

in the most recent call for POLAR proposals (2017–2019 cycle), in which four projects encompassing vegetation, hydrology, permafrost feedbacks and/or responses to climate change were selected. Several other funded projects within the current or past funding cycles at POLAR also have relevance to ABoVE (Table 2).

Space-based coordination with the Canadian Space Agency

POLAR and NASA are coordinating with the Canadian Space Agency, and indirectly with the World Meteorological Organization's Polar Space Task Group, to acquire satellite imagery for the ABoVE field sites, such as PALSAR-2, RADARSAT-2, Sentinel-1, and Terra SAR-X. In 2017, the Canadian Space Agency collected more than 500 swaths of RADARSAT-2 data (Fig. 6) to support research at field sites. The acquisitions had a 66% success rate because of competing national priorities and tasking conflicts. RADARSAT-2 employs C-band synthetic aperture radar (SAR), which can be used to measure the topography of landscapes at high resolution. This imagery is particularly crucial for flat terrain (e.g., the CHARS ERA), where it is often difficult to differentiate watersheds even with the guidance of local knowledge. More than 60 ABoVE researchers plan to use the RADARSAT-2 data for mapping environmental variables such as soil moisture, permafrost and active layer conditions, surface wetness, fire intensity, surface roughness, and vegetation characteristics. In some cases, these images will be used in conjunction with the airborne imagery collected by the 2017 ABoVE Airborne Campaign, while in other cases, the images will be used alongside field data collected in support of ABoVE. Through the use of these data, researchers are investigating rates of permafrost degradation, inundation changes, seasonal subsidence and thaw settlement, the response of lake levels to changes in permafrost conditions, and the detection of inundated vegetation, all in support of understanding the vulnerability and resilience of Arctic and boreal ecosystems to environmental change.

Figure 5: Researchers at High Arctic field sites; contrasting landscapes — alpine (left), tundra plateau (right); wind- and solar-powered monitoring station (centre) for the POLAR-funded Arctic Research Foundation's Cat-Train project.

Table 2: POLAR-supported projects related to the ABoVE program (available from https://www.canada.ca/en/polar-knowledge/advancingpolarknowledge.html).

Principal Investigator; Organization	Project Title	Region of Study
Asselin; Université du Québec de Abitibi-Témiscamingue	Impacts of climate change on wildfire risk in boreal forests in Northwest Territories	Communities across NWT
*Calmels; Yukon College	Mapping permafrost vulnerability in Vuntut Gwitchin Traditional Territory: climate change impacts on landscapes and hydrology	Old Crow, Yukon Territory
Stantec & Fraser; NRCan	Shrub Monitoring in Canada's Arctic using Multi-scale Measurements from Field Plots, Unmanned Aerial Vehicle (UAV) Surveys, and Satellite Remote Sensing	Regions in Nunavut & NWT
*Humphreys; Carleton University	Improving Canada's climate change projections by incorporating Arctic shrub feedbacks	Daring Lake Tundra Ecosystem Research Station, NWT
*Langlois; Université du Québec de Sherbrooke	Development of a multi-scale cryosphere monitoring network for the Kitikmeot region and Northwest Territories using modeling and remote sensing	Nunavut (Cambridge Bay, Gjoa Haven, Kugluktuk, Kitikmeot region)
Marsh; Wilfrid Laurier University	Cryosphere, vegetation, and freshwater monitoring in the western Canadian Arctic	Northwest Territories
Marshall; University of Calgary	Cryosphere-climate monitoring	Kluane Lake Research Station, Yukon Territory
*Quinton; Wilfrid Laurier University	Consortium for permafrost ecosystems in transition (CPET)	Scotty Creek & Suhm Creek, NWT
Rautio; Université du Québec à Chicoutimi	Ecosystem health of Arctic freshwaters	Cambridge Bay, Nunavut

Principal Investigator; Organization	Project Title	Region of Study
Sharam; Environmental Resource Management	What mechanisms drive habitat choice by caribou? A resource selection function approach using Traditional Knowledge, remote sensing and field surveys	Nunavut, NWT (Hope Bay, Back River, Ekati, Courageous Lake)
Tank; University of Alberta	Fire in the Arctic: The interactive effects of landscape, hydrology, and permafrost	Spence, Notawokha, Scotty, Boundary, and Baker Creeks; Northwest Territories
Zhang; Natural Resources Canada	Mapping and monitoring land surface and permafrost conditions along the Inuvik-Tuktoyaktuk Highway (ITH) corridor using satellite data and process-based modelling	Inuvik-Tuktoyaktuk Highway (ITH) corridor, NWT

* Project funded in POLAR's ABoVE category of the 2017 open call for proposals

Current activities are planning for additional RADARSAT-2 image acquisitions this summer (2018) to provide repeat acquisitions in most study sites, the inclusion of sites that were not able to be acquired in 2017, and new sites as research questions evolve.

Community considerations

In May 2016, NASA and POLAR co-sponsored a joint workshop, with the assistance and sponsorship of the Northwest Territories government. The workshop was attended by over 100 representatives of First Nations communities, federal and territorial governments, universities, industry, and NGOs. The goals of the workshop were to identify key management and research needs and questions, exchange information on ongoing and planned research and monitoring, solicit feedback on the POLAR Integrated Research and Monitoring Plan, review and discuss best practices for engaging and including communities and Indigenous knowledge holders in research and monitoring activities, and explore opportunities for collaborations on responding to the identified questions. The workshop was considered by local participants to be an important step in moving the project forward in Canada; workshop proceedings were published in a report available from POLAR (available from https://above.nasa.gov/implementation_plan/ETS_april2017.html).

After the Yellowknife workshop in May 2016, consultations were held with most of the First Nations groups included in the ABoVE domain in the Northwest Territories. These talks and meetings were recognized as demonstrating respect for the First Nations groups, deepening understanding of their needs and concerns, and planning future support through community-based monitoring activities.

Summary and future phases of POLAR and the ABoVE program

The results of this extensive and historic experiment will be used in related computer modelling efforts to help monitor and predict future scenarios across a range of Arctic ecosystems, from Low Arctic boreal forests to High Arctic tundra plateaus. Technology development through ABoVE will enable greater geographic coverage of the vast, remote Arctic landscapes for future monitoring and study. New and evolving partnerships between NASA, POLAR, and the many related organizations will lead to greater leveraging of limited resources to conduct such work in the Arctic.

Acknowledgements

We thank the Canadian Space Agency for its support in providing RADARSAT-2 imagery to ABoVE researchers and coordinating with the World Meteorological Organization's Polar Space Task Group for related satellite resources.

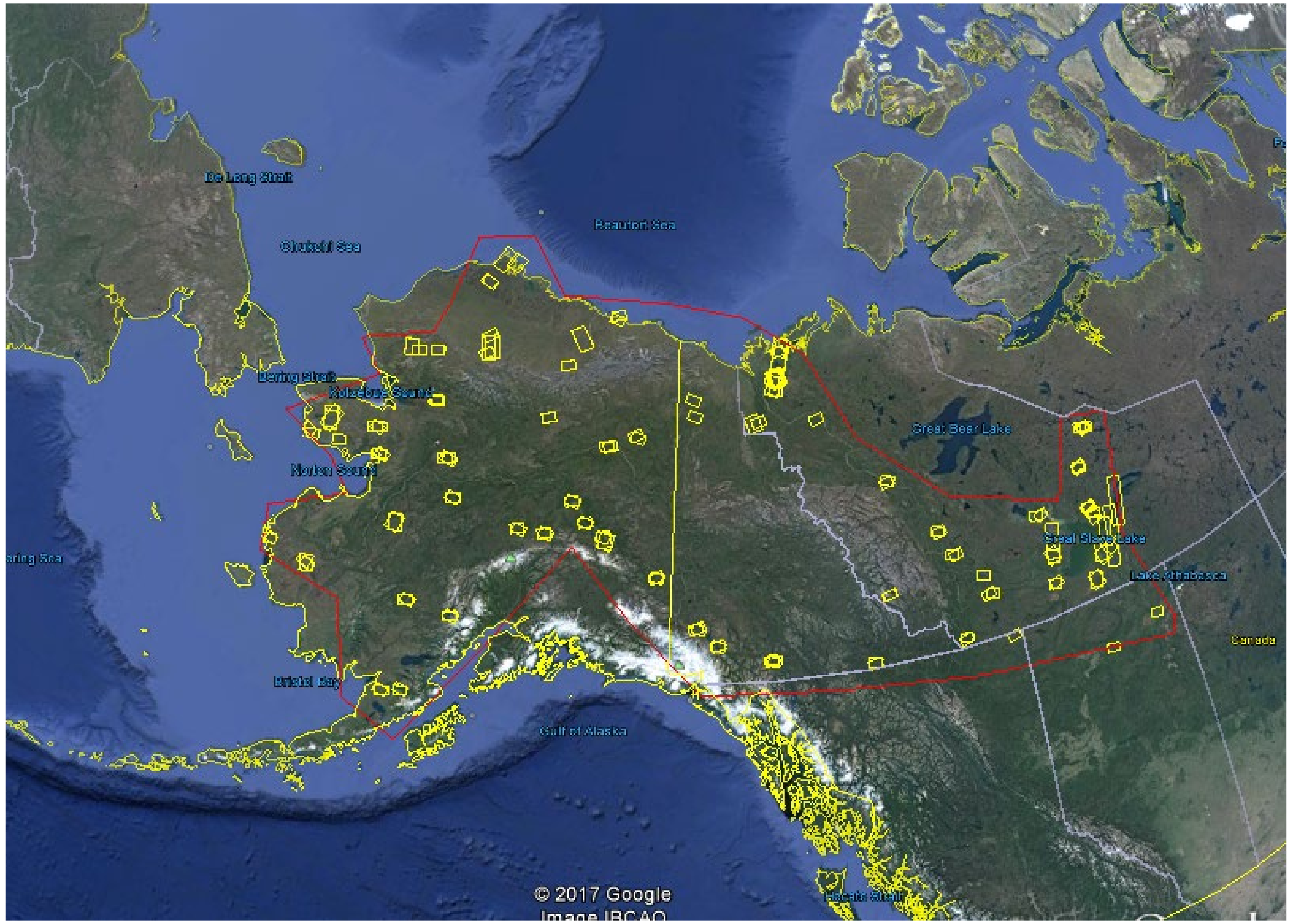


Figure 6: RADARSAT-2 image acquisitions within the ABoVE domain for 2017.

References

Lee, J.A., Stroves, B.K., and Lin, V. 2007. C-20A/GIII precision autopilot development in support of NASA's UAVSAR program. In Proceedings of the NASA Science Technology Conference 2007, Adelphi, Md., 19–21 June 2007. Dryden Flight Research Center, Report DFRC-658, 2007. 4 pp. Available from http://esto.nasa.gov/conferences/nstc2007/papers/Lee_James_B4P3_NSTC-07-0013.pdf.

Miller, C., Griffith, P., Goetz, S., Hoy, E.E., Pinto, N., McCubbin, I., and Margolis, H. 2018. An overview of ABoVE airborne campaign data acquisitions and science opportunities. Environmental Research Letters, In review.

NASA ABoVE Airborne Science. 2017. Available from https://above.nasa.gov/airborne_2017.html.

NASA ABoVE Concise Experiment Plan. 2014. Available from https://above.nasa.gov/acep.html.

NASA ABoVE Earth to Sky Course. 2017. Available from https://above.nasa.gov/implementation_plan/ETS_april2017.html.

POLAR Research and Projects. Available from https://www.canada.ca/en/polar-knowledge/advancingpolarknowledge.html.

THE CANADIAN ARCTIC MONITORING AND PREDICTION SYSTEM (CAMPS): A proposal for a coordinated knowledge system to understand and anticipate change in Canada's northern ecosystems

Donald S. McLennan[1 *]

[1] *Science and technology, Polar Knowledge Canada*

* *donald.mclennan@polar.gc.ca*

Abstract

It is now well documented that Canada's North is changing and these changes are having and will continue to have important impacts on communities, on the mandates of government agencies, and on understanding and mitigating impacts of industrial development. Due to systemic issues with research delivery, our present state of knowledge is limited both spatially and temporally, and is insufficient to provide the depth and breadth of knowledge required to monitor, understand, and predict change; reduce the potential for ecological surprise; and inform proactive adaptive management decisions. The Canadian Arctic Monitoring and Prediction System (CAMPS) is a proposal to initiate a national dialogue among all northern actors towards the development of a strategic northern knowledge system that would aim to coordinate ongoing science initiatives to optimize present investments, propose new strategic science investments, and mobilize the intellectual capital of Indigenous knowledge (IK) that is present in northern communities. Key elements of CAMPS include (1) long-term, strategic investments to sustain northern research infrastructure and support coordinated, multiscale, long-term, hypothesis-based monitoring experiments for northern terrestrial and freshwater ecosystems; (2) long-term investments in northern communities to build local capacity and engage IK so that science-community partnerships can be established and communities can act as a coordinated network of ecosystem observatories; and (3) coordination of these initiatives with ongoing monitoring by government agencies, universities, land claim bodies, communities, and industry to develop regional to national assessments of ecological change in Arctic and Subarctic ecosystems, and make predictions on near- and long-term change. It is proposed that an effective path forward would be to plan and develop a regional-scale implementation of CAMPS as a proof of concept to demonstrate the feasibility and usefulness of the proposed approach.

Introduction: Knowledge needs in a changing Arctic

It is well acknowledged that climate is warming much more rapidly in the Arctic and Subarctic than in southern latitudes (IPCC 2014; Serreze et al. 2009) — warming that is driving important changes in the abiotic-biotic interactions that in large part determine the abundance and health of many northern species (Settele et al. 2014). In Arctic coastal-marine systems, a decreased sea-ice season and warmer seawater are directly impacting sea-ice-dependent biota (Eamer et al. 2013; AMAP 2017), while sea-level rise and increased rates of coastal erosion (Forbes 2011; Gunther et al. 2015; Lantuit et al. 2015) are impacting vulnerable coastal wetlands that provide critical staging and nesting habitats for many migratory shorebird and waterfowl species (Provencher et al. 2018; Jorgensen et al. 2018). The degradation of permafrost on exposed lakeshores and riverbanks, and the deepening of soil-active layers, are impacting biota in freshwater systems (Balzer et al. 2014; Sniderhan and Balzer 2016) and changing the quality and quantity of river discharge to coastal marine ecosystems — a key determinant of physical processes that directly and indirectly affect coastal marine species (Frey et al. 2009; Carmack et al. 2016; Alkire et al. 2017). In terrestrial ecosystems, warming air and soil temperatures, degrading permafrost, and reduced snow season are causing infilling and changes in the relative dominance of shrubs, with unknown habitat effects (Myers-Smith et al. 2011; Tape et al. 2006, 2012). In some areas, historical lemming cycles are reduced or have crashed, with potentially cascading effects on the many species that prey on them (Schmidt et al. 2014). Northern caribou populations are at historic lows (Gunn et al. 2010; Parlee et al. 2018; CARMA 2018) and disease-driven muskoxen diebacks are occurring in the western Arctic — trends that at this time are largely unexplained (Kutz et al. 2015). Other factors, such as ocean acidification (Steinacher et al. 2009; Yamamoto-Kawai 2009), increased contaminants (Schuster et al. 2018), invasion by southern species (Lawler et al. 2009), and increased tourism, military activity, and industrial development all have the potential to significantly impact northern biota.

What is clear at this time is that environmental change is ongoing, is accelerating, and is happening across all ecosystems of the Canadian North at different rates and with differing effects, depending on the regional setting. Taken together, these ongoing changes interact in complex ways across spatial and temporal scales to create high levels of uncertainty for government and regional agencies with biodiversity conservation mandates, communities dependent on wild harvest (i.e., country food) and healthy ecosystems, and industrial proponents and operators charged with minimizing and mitigating potential impacts of ongoing and proposed developments.

The need for a national-scale approach

As a result of the broad variability in geographic scope in Canada's northern ecosystems and the overall complexity of predicted changes and their interactions, it is proposed here that a national-scale strategic approach is needed to develop a deep understanding of how and why these changes are occurring, in order to anticipate change and help develop proactive adaptation strategies for the North. At the present time in northern Canada, monitoring and research that could contribute effectively to our understanding of these myriad changes is largely fragmented and uncoordinated. For example, many government departments conduct excellent research and monitoring programs that are implemented to fulfill their stated mandates, but these programs are poorly linked to related work by academic organizations, industry, or communities. Canada is fortunate to have a culture of active world-class northern scientists, and although some academic researchers have managed to maintain research sites that sustain long-term monitoring and research programs, they are by necessity limited temporally because of short-term funding arrangements and spatially because of the limited geographic scope of their research areas. Arctic communities hold a wealth of Indigenous knowledge (IK), and although some community-based monitoring is occurring across the Arctic and Subarctic, programs generally lack long-term sustainability and regional linkages, and in many cases, IK is not effectively mobilized.

These systemic problems in our northern research and monitoring structure mean that we are not in a position to understand or predict important changes at a scale relevant to the potential impact of the changes. For example, changes in terrestrial ecosystems, such as the relative dominance of shrubs, input of soil carbon to the atmosphere, arrival of new species, and length of the growing season are well documented locally. A critical question is, how are these local changes playing out on regional and national scales in terms of overall contributions of carbon to the atmosphere, changes in land feedbacks to climate, progress of northward-migrating species, and changes in habitat for wide-ranging species such as caribou? To provide answers to this multi-faceted question and others, a long-term, multi-scale experimental monitoring approach that coordinates northern science and IK resources is needed. This approach would implement these long-term, monitoring

Suggested Citation:

McLennan, D.S. 2018. The Canadian Arctic Monitoring and Prediction System (CAMPS): A proposal for a coordinated knowledge system to understand and anticipate change in Canada's Northern ecosystems. Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 63–69. DOI: 10.35298/pkc.2018.08*

experiments across a sustained observatory network, which would capture northern ecological variability in terrestrial, freshwater, and coastal-marine ecosystems. This approach would also build on and connect present programs and attract new investments, which would support a strategic national approach to monitoring and research in Canada's North. In addition to the required funding, a key challenge will be to coordinate the wide range of actors that can contribute to such a network, including federal governments, territorial governments, land claim institutions, communities, Indigenous organizations, industry, academics, and NGOs.

CAMPS: A proposal for a Northern knowledge system

The Canadian Arctic Monitoring and Prediction System (CAMPS) is a proposal to measure, understand, and predict biodiversity change, associated abiotic drivers, and ecological processes in a coordinated way, at a range of scales across the Arctic and Subarctic terrestrial, freshwater, and coastal-marine ecosystems of northern Canada. CAMPS can initiate a national dialogue among all northern actors, which can lead towards the development of a strategic northern knowledge system that will coordinate ongoing science and community initiatives. This coordination will optimize present investments, propose new strategic science investments as needed, and more effectively mobilize the intellectual capital and IK present in northern communities. Key elements of CAMPS include (1) long-term investments to sustain northern research infrastructure, utilizing and supporting the present array of research sites to establish a connected northern observatory network that would establish and maintain coordinated, long-term monitoring experiments; (2) long-term experiments established in the observatory network, which would be designed to quantify relationships among abiotic drivers, ecosystem processes, and targeted biotic outcomes (e.g., species of interest, habitat changes, changes in land/sea to atmosphere feedbacks), so that local-scale, process-based models could be developed and extrapolated to regional and national scales using remote-sensing tools; (3) long-term investments in northern communities to build local capacity and engage IK, establishing science-community partnerships that would implement a network of northern community observatories, especially in coastal-marine ecosystems; and (4) coordination of these new initiatives, with ongoing monitoring by government agencies, universities, land claim bodies, communities, and industry, in order to develop regional and national assessments of ecological change and the state of Arctic and Subarctic ecosystems, and make predictions on short- and long-term change.

CAMPS, as proposed, has three levels (Fig. 1). The foundation of the system is the northern observatory network, with a flagship monitoring site at the Canadian High Arctic Research Station (CHARS) as the hub. The observatory network would be initiated with existing northern research sites (e.g., research stations organized under the Centre d'études nordiques, the Canadian Network of Northern Research Operators, and the Changing Cold Regions Network) would monitor terrestrial and freshwater systems, and would be piloted in selected coastal communities, with supporting coastal boats (e.g., small craft from communities, small ships from the Arctic Research Foundation) and larger ships (e.g., Canadian Coast Guard icebreakers) for monitoring coastal marine ecosystems. Based on the input and direction of relevant science teams and IK experts, each site would implement and maintain coordinated, long-term monitoring experiments that link abiotic drivers and ecological processes to biodiversity outcomes in terrestrial, freshwater, and coastal-marine ecosystems. To develop consensus on the design and analysis of the long-term experiments, it is proposed that we convene subject-area experts to develop experimental approaches that reflect the latest best practices in their fields (e.g., for terrestrial monitoring, disciplines would include soil processes such as microbiology, soil physical processes, permafrost and nutrient cycling, vegetation change at a range of scales as well as faunal change in small mammals, shorebirds/songbirds, and arthropods).

The intermediate level of the system would work to access and incorporate surveillance monitoring data from the wide variety of mandate-based monitoring programs conducted by various northern federal and territorial government agencies, land claim co-management boards, industry, academic organizations, and community-based monitoring programs. With coordination, results from these programs could be used to calibrate and validate regional-scale, remote-sensing-based models that reach out from long-term monitoring experiments conducted through the observatory network.

The third and final level of CAMPS would use observatory data and regional and national models from the observatory network, species-specific or targeted monitoring data from government departments and academia, and other data from the intermediate level of mandate-based monitoring programs to develop remote-sensing-based models that would extrapolate local results to regional and national scales in order to make predictions of change using appropriate monitoring measures (e.g., changes in vegetation composition, structure, and productivity caused by climate-driven change in soil and site drivers; changes to freshwater systems brought about by accelerating permafrost degradation and changes in snow regime; and changes in sea-ice biota resulting from sea-ice changes and warming water).

Community considerations

The success of CAMPS will rely heavily on the meaningful engagement and involvement of northern community members, community and regional governing bodies, and associated Indigenous organizations. An important aspect of CAMPS is to build on and support the Indigenous knowledge and experience inherent in northern communities — knowledge and experience gained from centuries of observing and accessing natural resources. The proposed approach establishes community-science partnerships and develops a network of northern communities to work as equal partners with researchers in the design, implementation, and dissemination of research while having access to information gathered about communities and control over how the information is used and disseminated (ITK 2016). Investments in community training, employment, and infrastructure, and meaningful input into the design of the long-term monitoring to be implemented, would contribute to self-determination and sustainable economies in participating communities.

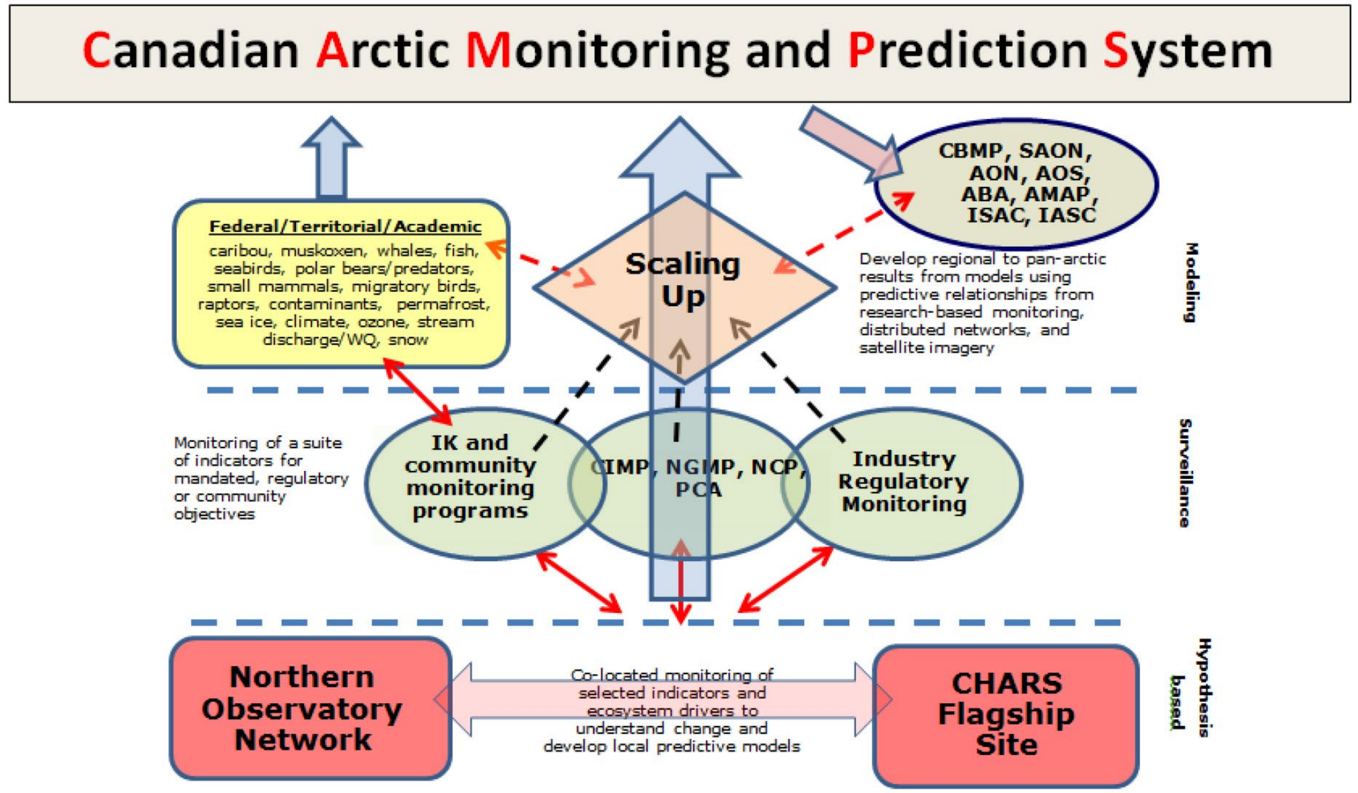


Figure 1: Schematic of the proposed Canadian Arctic Monitoring and Prediction Network (CAMPS) — see text for discussion. IK = Indigenous Knowledge; CIMP = Cumulative Impact Monitoring Program; NGMP = Nunavut General Mentoring Program; NCP = Northern Contaminants Program; PCA = Parks Canada Agency; CBMP = Circumpolar Biodiversity Monitoring Program; SAON = Sustained Arctic Observing Network; AON = Arctic Observing Network; AOS = Arctic Observing Summit; ABA = Arctic Biodiversity Assessment; ISAC = International Study of Arctic Change; IASC = International Science Committee.

Community-based research and monitoring is central to the success of CAMPS and includes two key activities: (1) activities initiated and implemented by the communities to address key community needs (supported by science as requested) and (2) activities that are part of regionally coordinated, science-based activities, where community members would be employed and receive training, science support, and equipment to conduct the monitoring. It is very important that information gathered using community-based monitoring approaches be collected through the use of standard protocols and designs so as to link effectively to regional CAMPS activities.

Discussion

Key to this proposal is the engagement and coordination of a range of northern actors on a scale that has not been achieved to date, and it is important not to underestimate the challenge in achieving such involvement. On the other hand, coordination across mandates, agencies, and organizations has been seen as a worthy goal by all actors for many years. Successful partnerships will be successful if they benefit all parties in relation to the investment each party makes in the proposed northern knowledge system. The Canadian North is vast, with poor access and large knowledge gaps, and all northern actors are limited in terms of the funding and expertise needed to understand the complex, interacting, and accelerating ecological changes that are happening. Although ambitious, such a coalition is absolutely necessary to achieve the goals of CAMPS.

In addition to meaningful community engagement, another key to the success of this proposal is to work towards securing long-term funding for the network of research sites that would implement the coordinated experiments. This funding would make a significant contribution to "keeping the lights on" at research sites and providing training and employment support for northern technical staff who would maintain monitoring experiments over the long term. Such an investment would have the side benefit of helping to secure these sites for research science of all kinds, the results of which are needed to support the development and evolution of the coordinated, long-term monitoring experiments.

It is anticipated that implementation of CAMPS would occur regionally, to take advantage of existing regional partnership and activities, but a standardized approach to long-term experiments and the scaling up of models would permit national synopses of regional activities. If implemented, CAMPS would provide useful and timely information at a range of scales on ongoing and predicted changes in northern ecosystems, which would support proactive adaptation approaches for northern communities, industries, and governments. Investments in CAMPS would support academic research at a strategic network of northern research sites, provide capacity building to northern communities, support resilience and self-determination in these communities, and optimize present investments in northern science.

References

Alkire, M. B., Jacobson, A. D., Lehn, G. O., Macdonald, R. W., and Rossi, M.W. 2017. On the geochemical heterogeneity of rivers draining into the straits and channels of the Canadian Arctic Archipelago. *Journal of Geophysical Research: Biogeosciences* 122 (10):2527–2547. Available from http://doi.org/10.1002/2016JG003723.

Arctic Monitoring and Assessment Programme (AMAP). 2017. Snow, water, ice, and permafrost in the Arctic (SWIPA). Arctic Monitoring and Assessment Programme, Oslo, Norway. Xiv + 269 pp.

Baltzer, J. L., Veness, T., Chasmer, L. E., Sniderhan, A. E., and Quinton, W. L. 2014. Forests on thawing permafrost: Fragmentation, edge effects, and net forest loss. *Global Change Biology* 20:824–834. doi:10.1111/gcb.12349.

Carmack, E. C., Yamamoto-Kawai, M., Haine, T. W. N., Bacon, S., Bluhm, B. A., Lique, C., and Williams, W. J. 2016. Freshwater and its role in the Arctic marine system: Sources, disposition, storage, export, and physical and biogeochemical consequences in the Arctic and global oceans. *Journal of Geophysical Research: Biogeosciences* 121 (3):675–717. Available from http://doi.org/10.1002/2015JG003140.

CircumArctic Rangifer Monitoring and Assessment Network (CARMA). Available from https://carma.caff.is/herds [accessed March 2018].

Eamer, J., Donaldson, G.M., Gaston, A.J., Kosobokova, K.N., Lárusson, K.F., Melnikov, I.A., Reist, J.D., Richardson, E., Staples, L., and von Quillfeldt, C.H. 2013. Life linked to ice: A guide to sea-ice-associated biodiversity in this time of rapid change. CAFF Assessment Series No. 10. Conservation of Arctic Flora and Fauna, Akureyri, Iceland. ISBN: 978-9935-431-25-7.

Forbes, D.L. (ed.). 2011. State of the Arctic coast 2010: Scientific review and outlook. International Arctic Science Committee, Land-Ocean Interactions in the Coastal Zone, Arctic Monitoring and Assessment Programme, International Permafrost Association. Helmholtz-Zentrum, Geesthacht, Germany. 178 pp. Available from http://arcticcoasts.org.

Frey, K. E. and McClelland, J.W. 2009. Impacts of permafrost degradation on Arctic river biogeochemistry. *Hydrological Processes* 23 (1):169–182. Available from http://doi.org/10.1002/hyp.7196.

Gunn, A., Russell, D., and Eamer, J. 2010. Northern caribou population trends in Canada: Canadian biodiversity; Ecosystem status and trends. Technical Thematic Report No. 10, Canadian Councils of Resource Ministers of the Environment.

Günther, F., Overduin, P.P., Yakshina, I.A., Opel, T., Baranskaya, A.V., and Grigoriev, M.N. 2015. Observing Muostakh disappear: Permafrost thaw subsidence and erosion of a ground-ice-rich island in response to Arctic summer warming and sea-ice reduction. *The Cryosphere* 9:151–178.

Intergovernmental Panel on Climate Change (IPCC). 2014. Climate change 2014: Synthesis report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Core writing team, Pachauri, R.K. and Meyer, L.A. (eds.), IPCC, Geneva, Switzerland. 151 pp.

Inuit Tapiriit Kanatami (ITK). 2016–2019. Strategy and action plan. Available from https://www.itk.ca/wp-content/uploads/2016/03/English-2016-2019-Strategy-Plan.pdf.

Jorgensen, M.T., Frost, G.V., and Dissing, D. 2018. Drivers of landscape changes in coastal ecosystems of the Yukon-Kuskokwim Delta, Alaska. *Remote Sensing,* 10, pp 1-27. doi:10.3390/rs 10081280.

Kutz, S., Bollinger, T., Branigan, M. et al. 2015. *Erysipelothrix rhusiopathiae* associated with recent widespread muskox mortalities in the Canadian Arctic. *The Canadian Veterinary Journal* 56 (6):560–563.

Lantuit, H., Overduin, P., Couture, N., Wetterich, S., Aré, F., Atkinson, D., Brown, J., Cherkashov, G., Drozdov, D., Forbes, D., Graves-Gaylord, A., Grigoriev, M., Hubberten, H.W., Jordan, J., Jorgenson, T., Ødegård, R., Ogorodov, S., Pollard, W., Rachold, V., Sedenko, S., Solomon, S., Steenhuisen, F., Lantz, T.C., and Kokelj, S.V. 2008. Increasing rates of retrogressive thaw slump activity in the Mackenzie Delta region, Canada. *Geophysical Research Letters* 35, L06502. doi:10.1029/2007GL032433.

Lawler, J.L, Shafer, S.L., White, D., Kareiva, P., Maurer, E.P., Blaustein, A.R., and Bartlein, P.J. 2009. Projected climate-induced faunal change in the western hemisphere. *Ecology* 90 (3):588–597.

McLennan, D.S., Mackenzie, W.H., Meidinger, D.V., Wagner, J., and Arko, C. 2018. A standardized ecosystem classification for the coordination and design of long-term terrestrial ecosystem monitoring in Arctic-Subarctic biomes. *Arctic* 71(Suppl. 1):1–15.

McLennan, D.S. and Wagner, J. In prep. The Canadian High Arctic Research Station monitoring plan: Pilot phase for terrestrial ecosystems. CAFF Report, CAFF International Secretariat, Akureyri, Iceland.

Myers-Smith, I.H., Forbes, B.C., Wilmking, M., Hallinger, M., Lantz, T., Blok, D., Tape, K.D., Macias-Fauria, M., Sass-Klaassen, U., Levesque, E., Boudreau, S., Ropars, P., Hermanutz, L., Trant, A., Siegwart Collier, L., Weijers, S., Rozema, J., Rayback, S.A., Schmidt, N.M., Schaepman-Strub, G., Wip, S., Rixen, C., Menard, C.B., Venn, S., Goetz, S., Andreu-Hayles, L., Elmendorf, S., Ravolainen, V., Welker, J., Grogan, P., Epstein, H.E., and Hik, D.S. 2011. Shrub expansion in tundra ecosystems: Dynamics, impacts, and research priorities. *Environmental Research Letters* 6 (2011) 045509 (15pp). doi:10.1088/1748-9326/6/4/045509.

Parlee, B.L., Sandlos, J., and Natcher, D.C. 2018. Undermining subsistence: Barren-ground caribou in a "tragedy of open access." *Science Advances* 4:e1701611.

Provencher, J. V., Johnston, E., Syroechkovskiy, N., Crockford, N., Lanctot, R.B., Millington, S., Clay, R., Donaldson, G., Ekker, M., Gilchrist, G., Black, A., Crawford, R., Price, C., and Barry, T. 2018. Arctic migratory birds initiative (AMBI): Revised workplan 2015–2019. CAFF Strategies Series No. 6. Conservation of Arctic Flora and Fauna, Akureyri, Iceland. ISBN: 978-9935-431-72-1.

Schmidt, N.M., Ims, R.A., Høye, T.T., Gilg, O., Hansen, L.H., Hansen, J., Lund, M., Fuglei, E., Forchhammer, M.C., and Sittler, B. 2012. Response of an Arctic predator guild to collapsing lemming cycles. *Proceedings of the Royal Society B* 279:4417–4422. doi:10.1098/rspb.2012.1490.

Schuster, P. F., Schaefer, K.M., Aiken, G.R., Antweiler, R.C., Dewild, J.F., Gryziec, J.D., and Zhang, T. 2018. Permafrost stores a globally significant amount of mercury. *Geophysical Research Letters* 45. Available from https://doi.org/ 10.1002/2017GL075571.

Serreze, M.C., Barrett, A.P., Stroeve, J.C., Kindig, D.N., and Holland, M.M. 2009. The emergence of surface-based Arctic amplification. *The Cryosphere* 3:11–19.

Settele, J. et al. 2014. Terrestrial and inland water systems. In Climate change 2014: Impacts, adaptation, and vulnerability: Part A - Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., and White, L.L. (eds.), Cambridge University Press. pp. 271–359.

Sniderhan, A. E. and Baltzer, J.L. 2016. Growth dynamics of black spruce (*Picea mariana*) in a rapidly thawing discontinuous permafrost peatland. *Journal of Geophysical Research: Biogeosciences* 121:2988–3000. doi:10.1002/2016JG003528.

Steinacher, M., Joos, F., Frolicher, T.L., Plattner, G.K., and Doney, S.C. 2009. Imminent ocean acidification in the Arctic projected with the NCAR global coupled carbon cycle-climate model. *Biogeosciences* 6:515–533.

Streletskaya, I. and Vasiliev, A. 2015. The Arctic coastal dynamics database: A new classification scheme and statistics on Arctic permafrost coastlines. *Estuaries and Coasts* 35:383–400. doi:10.1007/s12237-010-9362-6, 2011a.

Tape, K., Sturm, M., and Racine, C. 2006. The evidence for shrub expansion in northern Alaska and the Pan-Arctic. *Global Change Biology* 12:686–702.

Tape, K.D., Hallinger, M., Welker, J.M., and Ruess, R.W. 2012. Landscape heterogeneity of shrub expansion in Arctic Alaska. *Ecosystems* 15:711–724. doi: 10.1007/s10021-012-9540-4.

Yamamoto-Kawai, M., McLaughlin, F.A., Carmack, E.C., Nishino, S., and Shimada, K. 2009. Aragonite undersaturation in the Arctic Ocean: Effects of ocean acidification and sea ice melt. Science 326 (5956):1098–1100.

THE ONE VOICE METHOD:
Connecting Inuit Qaujimajatuqangit with western science to monitor Northern Canada's freshwater aquatic environment

Richard A. Nesbitt[1*], Neil J. Hutchinson[2], Heidi E. Klein[3], Brenda L. Parlee[4], Jeff Hart[5], Jeff Tulugak[5], and Luis Manzo[5]

[1] *Hutchinson Environmental Sciences Ltd. Kitchener, Ontario, Canada*

[2] *Hutchinson Environmental Sciences Ltd. Bracebridge, Ontario, Canada*

[3] *Sanammanga Solutions Inc. Vancouver, British Columbia, Canada*

[4] *Department of Resource Economics and Environmental Sociology; Faculty of Agricultural, Life and Environmental Science; University of Alberta, Edmonton, Alberta, Canada*

[5] *Lands Department, Kivalliq Inuit Association, Nunavut, Canada*

* *richard.nesbitt@environmentalsciences.ca*

The One Voice Project is led by the Kivalliq Inuit Association (KIA) and Hutchinson Environmental Sciences Ltd. (HESL), and is supported by the community of Baker Lake. The One Voice Project is a component of "Inuu'tuti," the Baker Lake Aquatic Cumulative Effects Monitoring Program. Inuu'tuti is led by a governing Secretariat consisting of KIA (with technical support provided by HESL), the Nunavut General Monitoring Plan, and the Nunavut Water Board.

Abstract

Links between the Inuit Qaujimajatuqangit (IQ) and western science knowledge systems were explored through a series of modified semidirected interviews with knowledge holders, which were led by a "curious scientist" asking targeted questions to determine intersections for select water quality observations. Three iterative interviews were held, the last of which was on the land at sites identified by knowledge holders as having consistently high- or low-quality drinking water. Concurrent water quality sampling by the scientist helped establish a subset of analytes as common indicators that characterize the aquatic environment between the two knowledge systems. These common indicators can be used to establish baseline conditions, evaluate the impact of stressors, refine aquatic monitoring programs to better address community concerns, and produce a more holistic characterization of the aquatic environment, using both approaches.

Introduction

The livelihood of Canada's Indigenous populations is historically rooted in an intimate understanding of the natural environment. Recognition of that unique and comprehensive understanding of the local environment has been penetrating Canada's environmental legislation, policies, and practices for the past two decades (Usher 2000; CEAA 2012). For example, the Canadian Environmental Assessment Act requires the consideration and incorporation of Indigenous knowledge to facilitate a more complete characterization of large-

Suggested citation:

Nesbitt, R.A., Hutchinson, N.J., Klein, H.E., Parlee, B.L., Hart, J., Tulugak, J., and Manzo, L. 2018. The One Voice method: Connecting Inuit Qaujimajatuqangit with western science to monitor Northern Canada's freshwater aquatic environment. Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 70–77. DOI: 10.35298/pkc.2018.09*

scale development impacts (CEAA 2012). More recently, the Canadian federal government has introduced new environmental legislation that increases the obligation to consider the rights and knowledge of Indigenous people (i.e., Bill C-69 *An Act to enact the Impact Assessment Act and the Canadian Energy Regulator Act, to amend the Navigation Protection Act and to make consequential amendments to other Acts*).

While Indigenous knowledge is a required component of environmental impact assessments (EIAs), there is a wide but inconsistent variety of guidance on how it should be considered in conjunction with western science approaches that are the foundation of EIA (Bartlett et al. 2015). This problem is exacerbated by the typical framework through which the knowledge is collected. Semidirected interviews and consultations are relied on to gather the community's input on valued ecosystem components (VECs), but rarely do interviewers ask necessary follow-up questions to ensure the environmental information underlying the experiences and anecdotes offered by interviewees are adequately explored to provide details and context (Usher 2000). In addition, collecting information according to VECs is a western approach. Indigenous participants will repeatedly tell you that they do not see the world that way. Their view is holistic and cannot be separated into pieces (Legat 2012, Berkes 1998). VEC identification is embedded in practice and works somewhat effectively for wildlife, but falls short for less tangible VECs like water quality, which is rarely evaluated in its own right. In spite of the right to "no substantial alteration" accorded to water quality in Article 20 of the Nunavut Land Claims Agreement (NLCA 1993), EIAs on record frequently report impacts to water quality only in terms of implications to human health or effects on aquatic biota. The critical follow-up questions to explore water quality as an attribute in its own right have historically been left unasked, as interviews are led by IQ specialists or other professionals without a specific background in water quality. The lack of water discipline experience has allowed key descriptors of the aquatic environment to be overlooked, resulting in text akin to "no water quality information was specifically noted" (Sabina 2015), when in fact, the absence may reflect not the lack of information but the lack of appropriate questioning. Water quality is identified as a VEC through IQ, but without further detail its incorporation into environmental monitoring datasets and project design specifications is precluded. Western science has therefore remained the focus when evaluating project effects, even in jurisdictions like Nunavut where environmental co-management is integral to the assessment process, as mandated by the Nunavut Impact Review Board (NIRB 2016).

The overarching objective of this project was to address this deficit through the development of an approach to bring IQ and western science into One Voice to monitor the aquatic environment. This was accomplished through a series of semidirected interviews uniquely led by an aquatic environmental scientist with local experience around the community supported by Inuit researchers.

Methods

Three separate interviews were held from 2015 to 2017 with Inuit Elders[1] and hunters from Baker Lake, Nunavut, as part of the Innu'tuti program in the Baker Lake watershed. The study area was confined to the local watersheds near Baker Lake, as local Inuit engage in traditional land uses in proximity to the community. These watersheds are not pristine, but rather, are under some stress from operating gold mines, community sewage and garbage disposal, and climate change. Alterations to these watersheds have been taking place since the advanced exploration stage for the Meadowbank Mine in the early 2000s and the onset of a warming climate in the 1950s (Medeiros et al. 2012).

The interview approach was modified from *Voices from the Bay*, following a semidirective style (McDonald et al. 1997). Fixed questions were posed to knowledge holders with the support of local translators. Follow-up questions were posed during the interviews if responses hinted at descriptors of physicochemical water quality properties or were too broad, and required prompting by a "curious scientist" to gain further information. This water-quality-focused departure from the standard semidirected interview garnered additional detail from interviewees to establish more tangible linkages between reported observations and measurable western science variables. Iterative interviews were conducted with progressively focused objectives (Table 1). Parallel programs were conducted for the fish health and water quantity VECs, but insufficient data (scientific and IQ) was generated through the current study for inclusion in this discussion. Future investigations have been proposed to collect the requisite data.

1 Elders were selected by the KIA and identified as respected members of Baker Lake with significant knowledge pertaining to the aquatic environment. They ranged in age from 41 to 90 years old. DOI: 10.xxx

Table 1: Iterative interviews with progressively focused objectives for One Voice study — water quality component.

	Year 1: 2015-2016	Year 2: 2016-2017	Year 3: 2017-2018
Objectives - Water Quality	Identify key VECs in the aquatic environment and traditional Inuit uses associated with each.	Confirm key Inuit uses associated with each VEC in the aquatic environment and the associated IQ measurement indicators.	Simultaneously collect visual and physicochemical measurements along with observations of IQ knowledge holders for each VEC associated with a key Inuit use of the aquatic environment.
	Determine IQ indicators used to evaluate the quality of each VEC in the aquatic environment.	Refine IQ measurement indicators of the aquatic environment and determine overlap with measurable western science – "common indicators" between the two knowledge systems.	Correlate measurements collected by each knowledge system to determine how measurements collected by one is represented by the other.
	Identify conceptual thresholds for continuation of each use.	Identify characteristics of water and fish that are desirable and undesirable, and the locations where they occur.	Define characteristics of water representing normal conditions, and those indicating degradation or a divergence from them. Identify the IQ thresholds for discontinuing traditional uses of the aquatic environment.

Initial exploratory individual interviews in Year 1 (November 2015) were held with ten male knowledge holders and included general discussions on water quality, quantity, and flow (as per the Inuit rights to an unaltered aquatic environment under the 1993 NLCA) and the use of fish, waterfowl, and insects as aquatic indicators. Interviews in Year 2 (January 2017) included eight men from Year 1 and four women to better capture possible gendered differences. Questions were intended to confirm conclusions from Year 1; explore traditional land uses linked to the aquatic environment, with a focus on water quality, fish, and transportation; and refine the hypothesized IQ thresholds. Maps at a 1:85,000 scale depicting the terrain within a 50 km radius and a 100 km radius around the hamlet of Baker Lake were provided to participants to geographically focus discussions on the most frequented locations. Locations that interviewees indicated as having consistently high or low water quality were recorded in preparation for field investigations in Year 3. Interviews in Year 3 (August 2017) were held on the land with individual or pairs of knowledge holders; all were participants in the previous years of the program. Nine locations with high-quality water previously indicated and four locations with low-quality water indicated were visited. At each location, interviewees were asked to identify the site as having high or low water quality and describe the taste, look, smell, mouth feel, and overall impression of the water. Water samples were collected concurrently for laboratory analysis. Analytes were chosen to assess the organoleptic[2] microconstituents highlighted by interviewees. These analytes were assessed in the field (dissolved oxygen, electrical conductivity, pH, and water temperature) and laboratory (alkalinity, total suspended and dissolved solids, turbidity, major ions, nutrients, total and dissolved organic carbon, and total metals).

Results and discussion

Interviewees consistently identified three characteristics associated with the freshwater aquatic environment: water quality, water quantity, and fish/fisheries (Table 2). Interviewees were consistent in reporting key uses for each, the normal and usable environmental conditions required for those uses, and the conditions signalling environmental concerns. This finding is consistent with the findings of McDonald et at. (1997), that Inuit had a clear image of what were normal environmental conditions and what revealed abnormalities. The point at which a land user consciously acknowledges that environmental conditions have deviated from normal conditions is considered the IQ threshold of change (Table 2).

2 Organoleptic microconstituents act on or involve the interviewees' sense organs. Specific to this study, organoleptic microconstituents acted on interviewees' senses of taste, sight, smell, and touch (mouth feel).

Table 2: Inuit traditional water uses and IQ-based thresholds of environmental change.

Valued Ecosystem Component	Inuit Use	IQ Thresholds of Environmental Change
Water Quality	Hot beverages (tea, coffee)	Water is no longer acceptable for consumption or washing. This threshold may be based on taste, sight, smell or perceived impairment. Thresholds may also differ with season and differ with uses*.
	Drinking water	
	Cooking water	
	Washing	
Water Quantity	Transportation by boat	Changing methods of transportation and altered route access, or reduced safety.
	Access to traditional routes	
Fish and Fisheries	Harvesting fish	Significant decline in catch per unit effort.
	Consuming fish	Undesirable size, condition, fat content or appearance.

*e.g., Saline water is seen as undesirable for drinking water, but is desirable for boiling fish or caribou as it helps season the meat.

Interviewees used organoleptic and physicochemical characteristics to evaluate whether water was acceptable for consumption or other uses. Follow-up questions delved into the responses of knowledge holders, eliciting detailed descriptors of the water quality that could potentially be linked to scientific indicators. These "common indicators" are outlined in Table 3. Although similar terminology has been recorded in other studies conducted in Canada's North (Goldhar et al. 2013), they were not linked to organoleptic microconstituents measurable through western science.

The most desirable waters were those flowing over rocky substrates (Fig. 1c), and were described as being deeper (i.e., greater than 3 m), clear, cool, and "refreshing," and having "no taste, no smell" (Thomas Iksariq: personal communication). Interviewees in other studies specified a preference for water from familiar sources (Goldhar et al. 2013). Spence and Walters (2012) suggested this was due to a history of demonstrated safety at a given location from ongoing community usage and habituation to a given organoleptic profile. This was confirmed in the present study through evidence of frequent use at sites with high-quality drinking water; interviewees pointed out kakivaks (spears with three prongs for catching fish) and kettles left nearby for future use, as well as cabins of Baker Lake residents (Fig. 1a, 1b). We note that this observation is not generalizable to other communities; water quality in proximity to small human developments may be seen as less desirable in other contexts. This highlights the importance of collecting community-specific information when evaluating the perceived safety and risks of a water source.

Sites with high-quality water were grouped into two categories based on taste profiles. The water at some sites had no taste while others had water with some taste, though their descriptions ranged broadly between interviewees and sites. For example, some water tasted like "there's more rocks around the area" (James Kalluk: personal communication) while water at other sites had a "strong taste of vegetation" (Jamie Seeteenak: personal communication). Interviewees had difficulty describing the specific profile at several sites where taste was noted. Similar observations appear in the literature, whereby even trained tasters consistently report a perceptual characteristic from the combined effect of the microconstituents, but have difficulty articulating the taste profiles (Burlingame et al. 2017). Specific reported tastes are further complicated by individual sensitivities as well as the sex, age, health, and smoking history of an individual (Burlingame et al. 2017). Sites with a reported taste had a greater concentration of total dissolved solids and a higher proportion of parameters (particularly organoleptic parameters such as calcium and sulphur) at detectable concentrations than those without taste (Fig. 2a, 2b). Of the other analyzed microconstituents, no specific parameter was consistently higher across those sites; the data has not been summarized here.

Table 3: Common indicators between IQ and western science to evaluate freshwater quality.

Taste and smell	Taste of "land"	Organic carbon	pH
		Conductivity	Nutrients
		Chlorophyll a	
	Saltiness	Salinity	Chloride
		Sodium	Hardness
		Alkalinity	Conductivity
	Fishy smell	Specific algal community	Chlorophyll α
		Nutrients	
	Water is "refreshing"	Total suspended solids	Total dissolved solids
		Salinity	Conductivity
		Chloride	pH
		Turbidity	Hardness
		Copper	Iron
		Manganese	Sodium
		Flow	Oil and grease
Water temperature	Assessment of water temperature by touch or taste	Water temperature	

Of the sites interviewees preferred not to drink from, two were turbid: "the murkier, the less you want to drink it" (Thomas Iksariq: personal communication; Fig. 1e). These two sites had the highest turbidity and total suspended solids, indicating participants were able to discern concentrations as low as 2.89 mg/L (Fig. 2c, 2d). These sites also had the greatest percent of parameters above the detection limit (Fig. 2b). Two other sites were

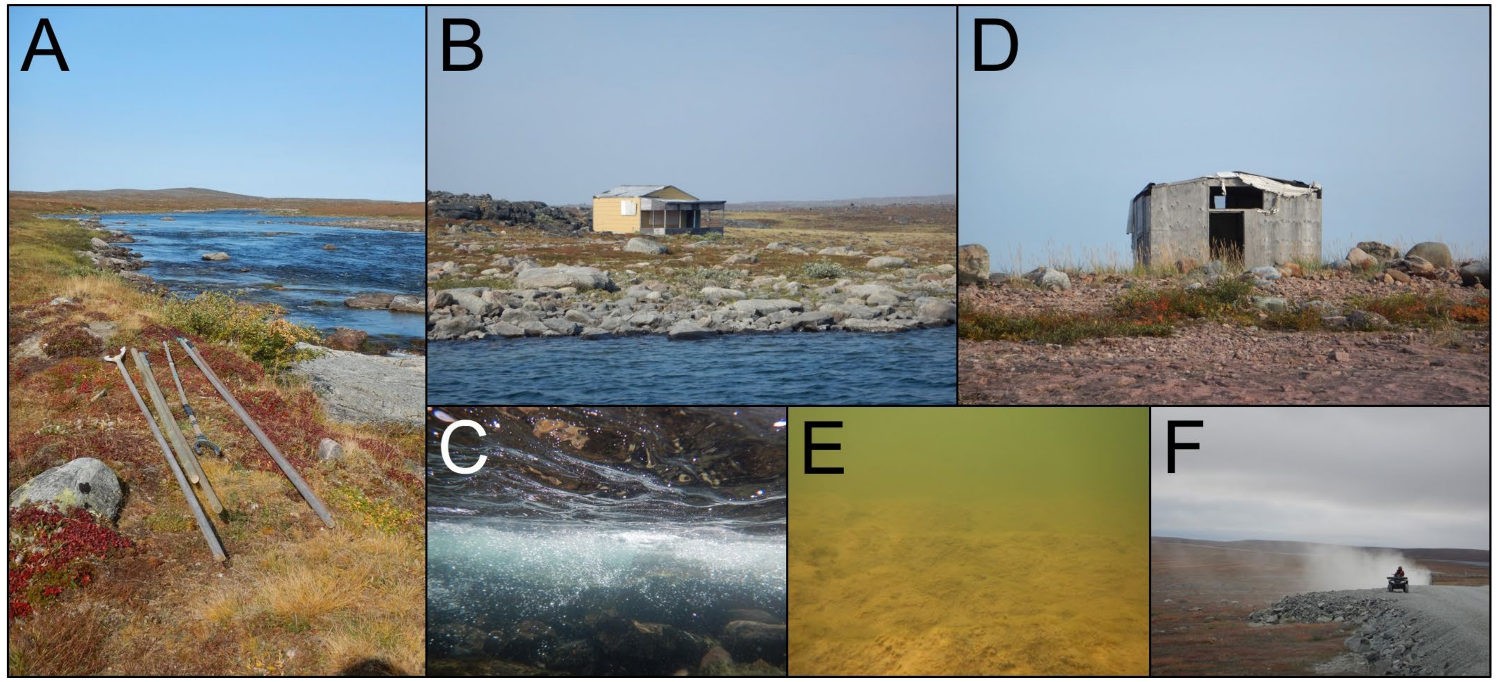


Figure 1: Photographs of sites with high-quality water (a, b, c) and low-quality water (d, e, f).

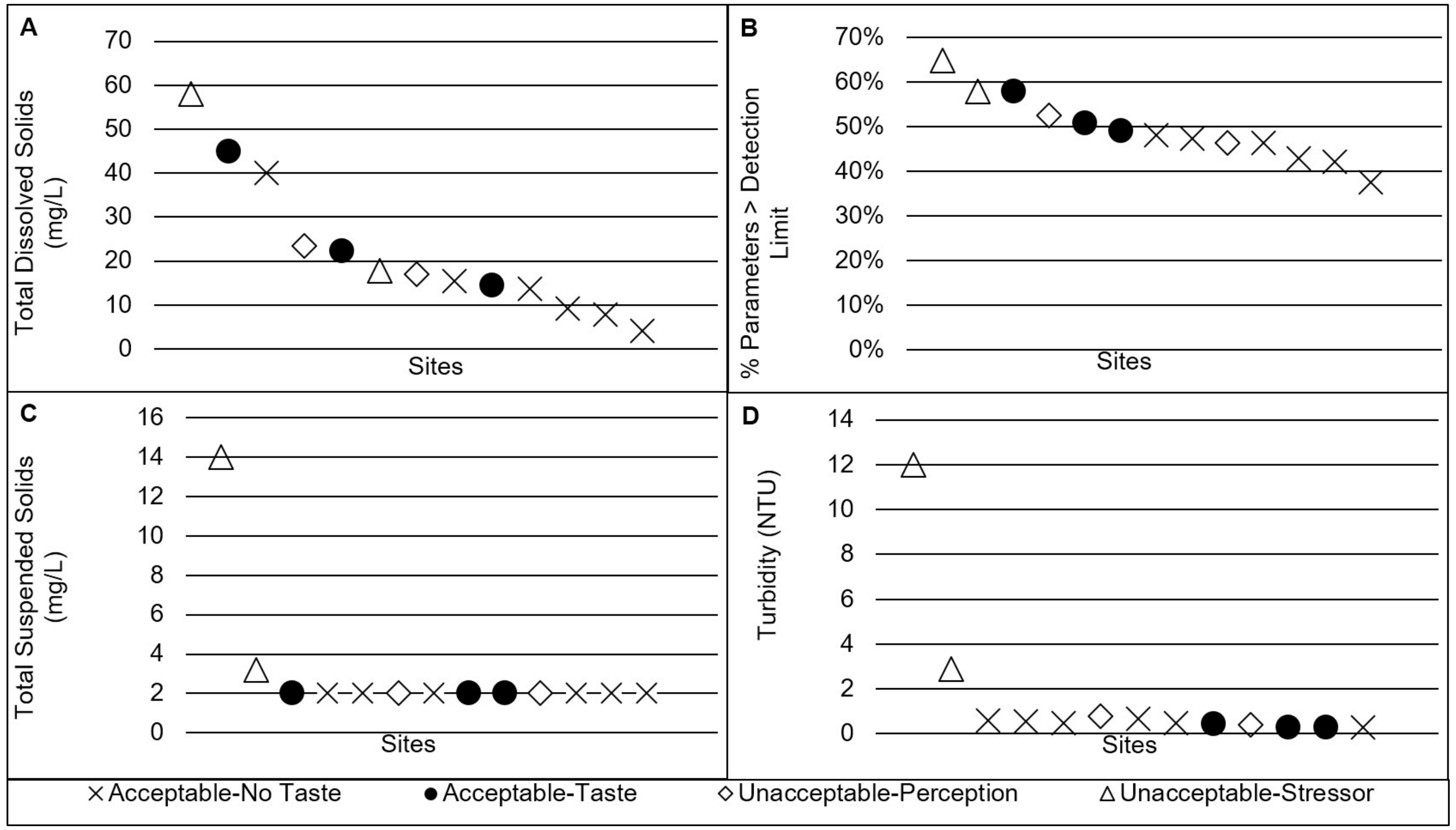


Figure 2: Water chemistry results from samples collected, concurrent to IQ interviews: (a) total dissolved solids, (b) percent of parameters above the detection limit, (c) total suspended solids, and (d) turbidity. Site categorizations are consistent across the figure.

identified as undesirable because of proximity to human activities; one site was in proximity to a disused cabin (Fig. 1d) while the other had inflows from a headwater area in which domestic sewage and garbage were dumped. These sites had visually pristine water (clarity did not differ from the acceptable sites), but interviewees had pre-existing knowledge indicating the water might be contaminated upstream. This is consistent with other studies where the knowledge of land uses near a water source influenced the perception of current safety (de França Doria 2010). In the latter example a dusty mine road (Fig. 1f) could be seen from the site close to the disused cabin, but the site was beyond the range of the dust fall (AEM 2017), while a sewage lagoon was associated with the other site, even though water was not flowing at that time (Fig. 1c, 1d).

Conclusions

Historical qualitative observations on the land can serve as a sentinel for change and impacts on the aquatic environment. Interviewees were sensitive to changes in taste, smell, mouth feel, turbidity, and temperature. While reports of such change . cannot be used to determine the magnitude of a change or the microconstituents involved, these reports can signal a shift in water chemistry and flag locations for future detailed analysis. Changes in proximity to land use can meaningfully impact people's use of the aquatic environment, regardless of whether that change is intermittent or having a measurable impact. Perceived changes in the environment as well as measurable changes in water quality may alter Inuit behaviour on the land, and should be considered as a real impact of development when conducting an environmental assessment and making land use decisions.

While the results are preliminary, Inuit knowledge of their water sources and their ability to describe the relevant characteristics in terms of preferred taste, smell, mouth feel, temperature, and appearance set a foundation for improved quantification using IQ and western science together in One Voice. If future work can identify an IQ-based threshold of change in the measurable perceptual characteristics of water, then such changes could be considered as quantifiable inputs to the environmental assessment process, with direct relevance to Inuit land use.

Community considerations

Community assessment of the common indicators is intended to empower Nunavummiut to evaluate the impact of stressors on their local aquatic environment, provide meaningful input to aquatic monitoring and contribute to a more holistic characterization of the valued ecosystem components.

Acknowledgements

We gratefully acknowledge the consultants from Baker Lake for sharing their stories and knowledge: Michael Akilak, Mrs. Alooq, Thomas Anirniq, Winnie Attungala, Timothy Evvuik, Thomas Iksariq, Tuupik Iyago, James Kalluk, Hannah Killulark, Simeon Mikkungwak, Thomas Oovayuk, David Owingayak, Jamie Seeteenak, and Irene Tiktaalaaq. We hope that we have compiled and interpreted their words respectfully, accurately, and completely. We also thank the Kivalliq Inuit Association for its ongoing leadership on Inuu'tuti, and both Polar Knowledge Canada and the Nunavut General Monitoring Program for their financial support.

References

Agnico Eagle Mines Ltd. (AEM) — Meadowbank Division. 2017. 2016 all-weather access road dust monitoring report.

Bartlett, C., Marshall, M., Marshall, A., and Iwama, M. 2015. Integrative science and two-eyed seeing: Enriching the discussion framework for healthy communities. In Ecosystems, society and health: Pathways through diversity, convergence, and integration, chap.10, Hallstrom, L.K., Guehlstorf, N., and Parkes, M. (eds.), McGill-Queen's University Press.

Berkes, F. 1998. Nature of traditional ecological knowledge and the Canada-wide experience. Terra Borealis 1:1–3. Available from http://nafaforestry.org/forest_home/documents/TerraBorealis1997.pdf [accessed 29 April 2018].

Burlingame, G.A., Doty, R.L., and Dietrich, A.M. 2017. Humans as sensors to evaluate drinking water taste and odor: A review. *Journal American Water Works Association* 109 (11):13–24.

Canadian Environmental Assessment Act (CEAA). 2012. c. 19, s. 52.

de França Doria, M. 2010. Factors influencing public perception of drinking water quality. *Water policy* 12 (1):1–19.

Goldhar, C., Bell, T., and Wolf, J. 2013. Rethinking existing approaches to water security in remote communities: An analysis of two drinking water systems in Nunatsiavut, Labrador, Canada. *Water Alternatives 6 (3):462–486.*

Inuit of Nunavut Settlement Region and Her Majesty the Queen. 1993. Nunavut Land Claims Agreement. Available from <http://nni.gov.nu.ca/sites/nni.gov.nu.ca/files/06NLCA-Eng.pdf> [accessed 28 March 2018].

Legat, A. 2012. Walking the land, feeding the fire: Knowledge and stewardship among the Tlicho Dene, University of Arizona Press.

McDonald, M., Arragutainaq, L., and Novalinga, Z. (eds). 1997. Voices from the bay: Traditional ecological knowledge of Inuit and Cree in the Hudson Bay bioregion. Canadian Arctic Resources Committee and Environmental Committee, Ottawa.

Medeiros, A., Friel, C., Finkelstein, S., and Quinlan, R. 2012. A high-resolution multi-proxy record of pronounced recent environmental change at Baker Lake, Nunavut. *Journal of Paleolimnology 47 (4):661–676.*

Nunavut Impact Review Board (NIRB). 2016. Inuit qaujimajatuqangit. Available from <www.nirb.ca/inuit-qaujimajatuqangit> [accessed 21March 2018].

Sabina Gold and Silver Corp (Sabina). 2015. Back River project final environmental impact statement supporting volume 6: Freshwater environment.

Spence, N. and Walters, D. 2012. "Is it safe?" Risk perception and drinking water in a vulnerable population. *International Indigenous Policy Journal* 3 (3):267–298.

Usher, P.J. 2000. Traditional ecological knowledge in environmental assessment and management. *Arctic* pp.183–193.

ESTABLISHING BASELINE LIMNOLOGICAL CONDITIONS IN BAKER LAKE, NUNAVUT

Neil Hutchinson[1*], Kris R. Hadley[1], Richard Nesbitt[1], and Luis Manzo[2]

[1] *Hutchinson Environmental Sciences Ltd., Bracebridge, Ontario, Canada*

[2] *Kivalliq Inuit Association, Rankin Inlet, Nunavut, Canada*

* *neil.hutchinson@environmentalsciences.ca*

Abstract

The Government of Canada and the Kivalliq Inuit Association initiated the Baker Lake Cumulative Effects Monitoring Program, or "Inuu'tuti," to document responses to multiple stressors in the Baker Lake Basin using western science and Inuit Qaujimajatuqangit. Baker Lake has had no systematic limnological investigation beyond a series of profiles documenting saline waters at depth in 1965. A series of limnological surveys (August 2015, open water; May 2016, late-winter; and August 2017, open water) included depth profiles of field parameters, laboratory chemistry analyses using modern-day detection limits and elaboration of the algal community at six sites in Baker Lake. Mixing of saline intrusions from Chesterfield Inlet with surface waters confirmed Inuit observations of a salty taste in drinking water, while the presence of chrysophyte algae may explain Inuit observations of episodic "fishy" taste in Baker Lake waters. The results confirm those from the 1965 study and provide an improved baseline for future assessment.

Introduction

Climate change and developing industry have the potential to significantly alter aquatic environments in Nunavut. At present, local monitoring programs implemented by various proponents are not standardized and data are not routinely interpreted or presented. This represents a gap in freshwater baseline information, limiting the ability of communities, industry, and regulators to effectively manage aquatic resources in Nunavut. Accordingly, in 2014, the Kivalliq Inuit Association (KIA) and the Nunavut General Monitoring Plan initiated a program to develop and implement an aquatic cumulative effects monitoring framework for the Baker Lake Basin (later named "Inuu'tuti") in recognition of documented climate warming (Medeiros et al. 2012), established and proposed mines, and a growing population.

Baker Lake receives drainage from three major river systems (the Thelon, Kazan, and Dubawnt), which drain much of the central Arctic. Although the watershed is large (1877 km^2), culturally important to Nunavummiut, and the focus of the Inuu'tuti program, limited data are available to characterize its limnology. Johnson (1965) collected a single profile of major ions in April 1964 near Christopher Island and found a marked increase in salinity below the 20 m depth (Fig. 1). Three possible mechanisms were suggested; however, the most likely cause was deemed to be incursions of dilute seawater from Hudson Bay (Johnson 1965). Inuit Qaujimajatuqangit (IQ) has documented occasional salty taste in surface waters near the Hamlet of Baker Lake that coincided with a full moon and low river inflows to the lake (HESL 2017; David Owingayak: personal communication), suggesting that saline incursions may be associated with tidal influence. Analysis of fossil diatoms and chironomids from Baker Lake sediment cores inferred a 2°C increase in water temperature over the past 50 years. This was corroborated with instrumental records over the same period, showing that the lake has responded to the warming climate (Medeiros et al. 2012).

A comprehensive monitoring program was therefore undertaken to (a) establish a baseline of water quality in Baker Lake for comparison with future changes and (b) investigate the dynamics of salinity in the lake, as part of the ongoing Inuu'tuti monitoring program.

Suggested citation:

Hutchinson, N.J., Hadley, K.R., Nesbitt, R.A., and Manzo, L. 2018. Establishing baseline limnological conditions in Baker Lake, Nunavut. Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 78–83. DOI: 10.35298/pkc.2018.10*

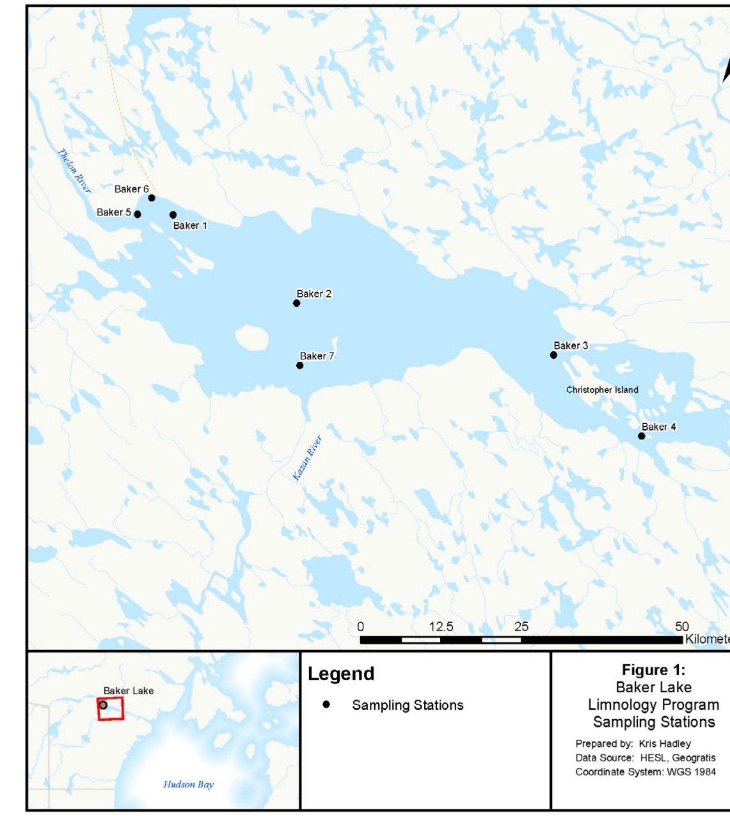


Figure 1: Baker Lake Limnology Program sampling stations.

Methods

Staff from Hutchinson Environmental Sciences Ltd. (HESL) and KIA monitored seven sites (Fig. 1) in Baker Lake in two open-water events (August 2015 and August 2017) and one under-ice event (May 2016), including four deep-water sites (Baker 1, 2, 3, 4), a nearshore site at the Baker Lake hamlet drinking water intake (Baker 6), and sites at the mouths of the Thelon River (Baker 5) and Kazan River (Baker 7). Profiles of water temperature, dissolved oxygen (DO), conductivity, and pH were measured at 1 m depth intervals from the surface to near the lake bottom at all seven locations using a YSI 6920 MP sonde. Samples were taken at 0.5 m from the surface and 1 m off bottom at Baker 1, 2, 3, 4, 6 and at 0.5 m at Baker 5, and 7. Laboratory analyses included major ions, nutrients, and trace metals to characterize lake chemistry; cyanide as a parameter of interest for gold operations in the basin; a selection of radionuclides in consideration of the potential for uranium mining (Baker 2 only, 0.5 m); and chlorophyll *a* and phytoplankton taxonomy to characterize algae and lake productivity (0.5m). Samples were stored in coolers containing ice packs immediately after sampling and shipped to ALS Laboratories in Yellowknife, Northwest Territories, for analysis. Phytoplankton samples were forwarded by ALS Yellowknife to ALS Winnipeg for taxonomic analysis to genus or species level.

Results and discussion

Three-year baseline water quality summary

Average August surface temperatures of 9°C–11°C in Baker Lake were consistent with the value of 10.5°C recorded by Medeiros et al. (2012). August temperature profiles in the deepest portion at the eastern end of Baker Lake (Baker 3) were consistent with weak thermal stratification during fall overturn. DO profiles showed concentrations of 10.1 to 15.9 mg/L, dependent on depth, water temperature, and salinity (Fig. 2).

Baker Lake is clear (turbidity <1 NTU), soft water (conductivity <100 µS/cm), low alkalinity (8.7–14.7 mg/L as $CaCo_3$), and nutrient-poor with low productivity. Total phosphorus concentrations averaged 4.8 +/- 1.4 µg/L in both surface and bottom water samples, with no marked spatial differences across the lake, and ortho-phosphate concentrations were at or below detection (< 1 µg/L) at all sites. Nitrogen levels were consistently low, with concentrations near or below detection in the majority of samples for total ammonia (<0.01 mg/L), nitrate (<0.06 mg/L), and total Kjeldahl nitrogen (<0.4). Chlorophyll *a* (Chl *a*) concentrations averaged 0.85 +/- 0.55 µg/L, consistent with oligotrophic (nutrient-poor and low primary productivity) conditions (i.e., Chl *a* <2.6 µg/L, Carlson and Simpson 1996).

Metal concentrations were low and typical of dilute Arctic waters. Water samples were analyzed for a suite of 38 metals, of which 19 were detected and none exceeded guidelines for drinking water quality (Health Canada 2014) or guidelines for the protection of freshwater aquatic life (CCME 1999). Sodium concentrations in Baker 3 and Baker 4 bottom samples exceeded the aesthetic water quality objective of 200 mg/L in 2015, consistent with the presence of saline marine waters and

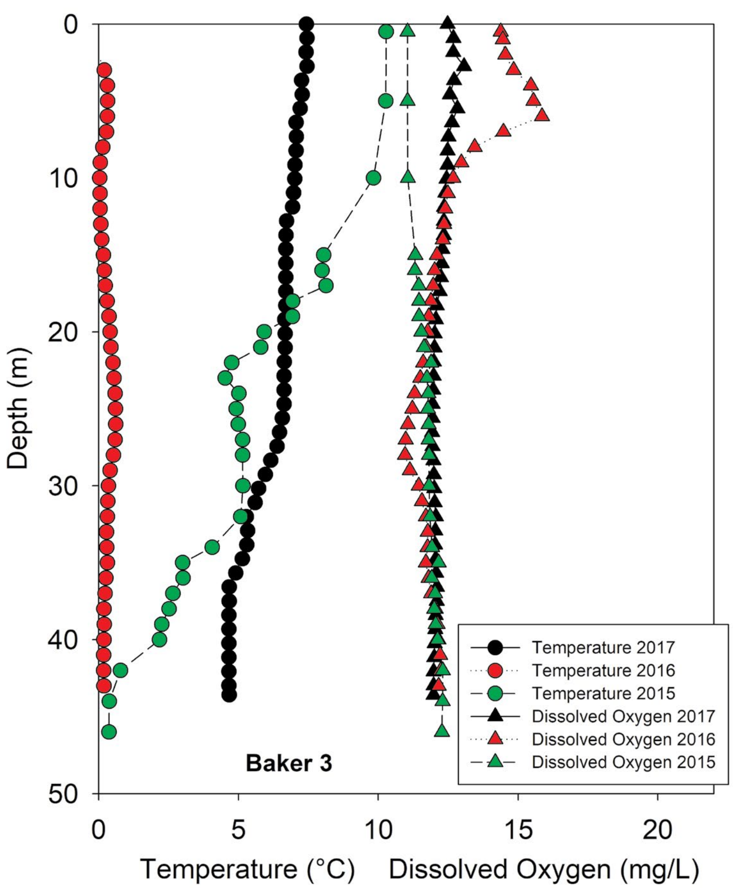


Figure 2: Representative profiles of temperature and dissolved oxygen at east end of Baker Lake in August 2015, May 2016, and August 2017.

IQ identification of taste issues with the water during the open-water season (HESL 2017; Tuupik Iyago: personal communication).

The algal community was dominated by small golden algae (chrysophytes), which comprised 37%–84 % of the species enumerated across all sites and sampling seasons (Fig. 3). Chrysophytes are efficient competitors in harsh conditions such as low nutrients, low temperatures, and unpredictable climates, common conditions in the Canadian Arctic (Wilkinson et al. 1996). Some chrysophyte species, specifically *Synura petersenii* and *Uroglena americana*, have been linked to taste and odor issues (Nicholls 1995; Watson et al. 2001), and may explain the occurrence of a fishy taste and smell in the surface water noted by community members in Baker Lake.

Other noteworthy phytoplankton genera that contributed significantly (>5%) to the Baker Lake assemblages included the planktonic diatoms *Asterionella* and *Cyclotella*. *Asterionella formosa* is one of the most common planktonic diatoms in northern hemisphere lakes and was identified in Baker Lake during both August surveys. The occurrence of *A. formosa* can also reflect enhanced stratification, a longer ice-free period, and a longer growing season as a result of a warming climate, irrespective of trophic status (Hadley et al. 2013;

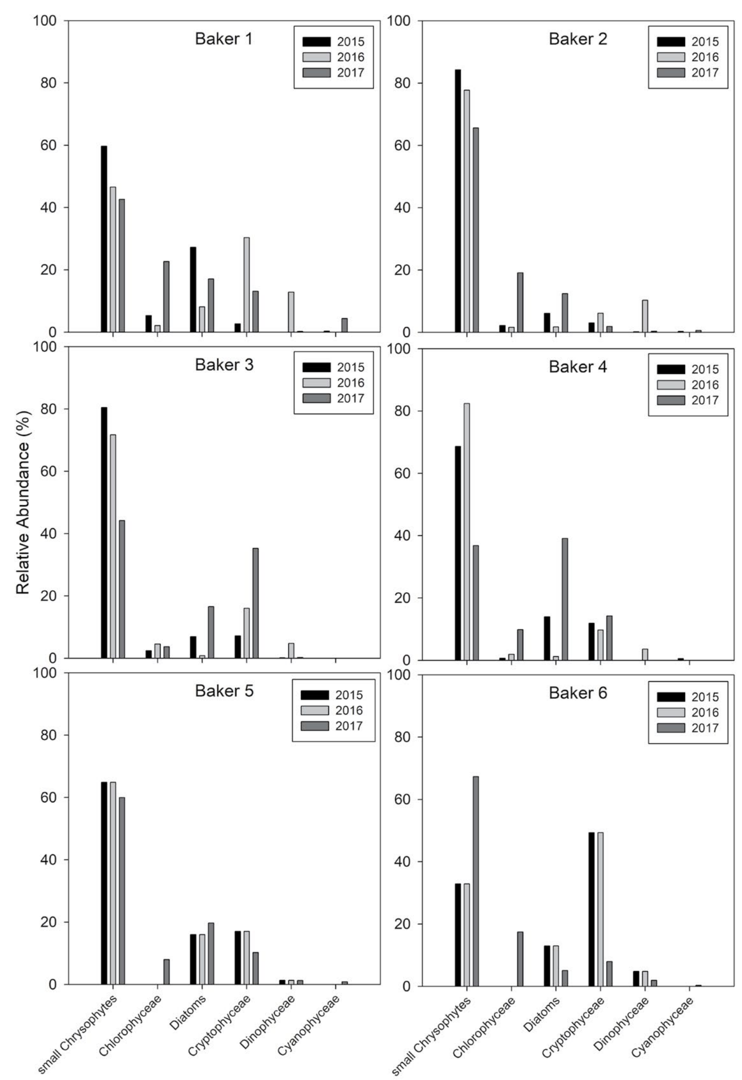


Figure 3: Phytoplankton community composition in Baker Lake in August 2015, May 2016, and August 2017.

Solovieva et al. 2008). *Asterionella* species were not reported during previous limnological studies of Baker Lake, suggesting this change may have occurred recently (Medeiros et al. 2012). Like *Asterionella*, *Cyclotella* species are common planktonic algae in stratified low-nutrient lakes. Cyanobacteria were identified in the majority of sites on Baker Lake but occurred in very low abundance (2-19 cells/mL).

Saline incursion in Baker Lake

Conductivity profiles (Fig. 4) and enriched concentrations of chloride and other major ions at depth indicated marine-water influences in Baker Lake. Marine influence was most pronounced in deep-water samples at Baker 1, 2, 3, 4, and there was no depth gradient close to the Thelon River (Baker 5,6). These data show that the seawater layer described by Johnson (1965) is widespread and not localized in the deepest basin of the lake nor to the eastern portion of the lake near the outflow to Chesterfield Inlet. Conductivity was lower under ice cover in 2016 than during open water in 2015 and 2017, consistent with IQ that saline taste issues with water near Baker Lake were more prevalent during the summer (HESL 2017; Tuupik Iyago: personal communication). Conductivity values at depth were uniform and low in the summer of 2017, varying by less than 100 µS/cm.

Source of saline water

Johnson (1965) postulated three explanations for the seawater incursion into Baker Lake: (1) ancient seawater trapped during isostatic rebound following glacial retreat; (2) seawater seeping through the sill at the outlet of the lake; or (3) seawater incursion over the sill of the outlet, driven by tides and storm activity.

The mixing of seawater into the water column (Johnson 1965) and the changes over time observed in our three-year monitoring program show that salinity was not isolated to the bottom waters of Baker Lake and the degree of salinity changed over time. Ancient origin of seawater is therefore not likely, as bottom waters would have been depleted of salt water by mixing over time, if remnant ancient marine waters were the only source of salinity.

Johnson (1965) suggested that underground seepage of seawater was an unlikely source based on the presence

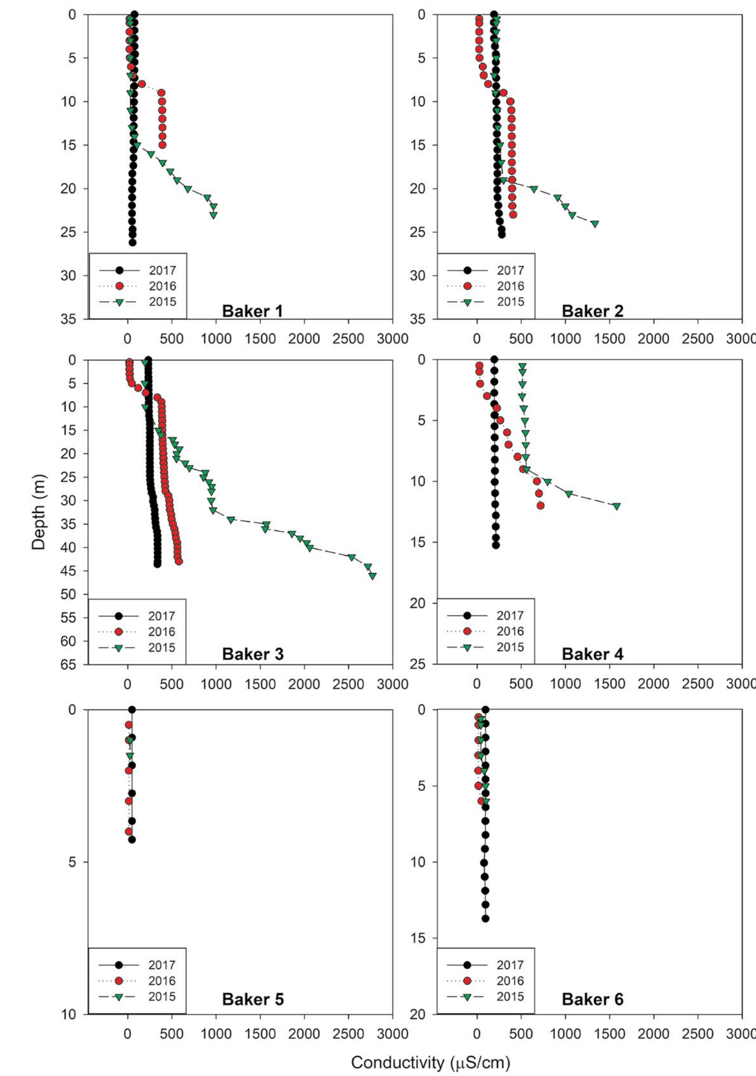


Figure 4: Conductivity profiles in Baker Lake in August 2015, May 2016, and August 2017.

of permafrost as a barrier to saline incursion. The presence of the large water masses of Baker Lake and Chesterfield Inlet, however, are likely to have formed a talik, which would be permeable to seepage, but the hydraulic gradient would generate from Baker Lake (18 masl) to Chesterfield Inlet (11 masl), and this gradient argues against seepage from Chesterfield Inlet through a talik.

The dynamic nature of salinity observed in Baker Lake suggests that the most likely source of saline water is periodic incursion over the sill separating the lake from Chesterfield Inlet. Chesterfield Inlet has stronger tidal currents, higher tidal amplitudes, and more mixing than elsewhere in Hudson Bay (Dohler 1968; Budgell 1976, 1982), and tides could therefore contribute salt water to Baker Lake (Stewart and Lockhart 2005). IQ observations of salty tasting water associated with lunar cycles and low river flows also suggest tidal influence as an important factor in bringing seawater into Baker Lake.

The dynamics of salinity in Baker Lake varied between the open-water surveys in August 2015 and August 2017 and the under-ice survey of May 2016. Significant flushing of the lake would have occurred between the 2015 and 2017 sampling events as a result of the 2016 and 2017 freshets. The melting snowpack accounts for the same amount of runoff during the two-week freshet period as during seven to eight months of precipitation, resulting in dramatic seasonal peak flows in the Thelon, Kazan, and Quoich River systems (Budgell 1976), which would flush the lake and prevent saline waters from accumulating from year to year. Lower summer water levels in Baker Lake would increase the influence of tidal inputs. Ice-mediated tidal dampening would restrict the inflow of seawater from Chesterfield Inlet in winter (NOAA 2011; Georgas 2011), and reduced wind mixing under ice would limit the extent of any saline intrusion. The expression of marine influence in Baker Lake is therefore a complex dynamic between water levels in the lake, tidal influence from Chesterfield Inlet, wind mixing, freshwater inflows to Baker Lake, and ice cover on the lake and Chesterfield Inlet.

Conclusions

The surface water quality of Baker Lake was indicative of a nutrient poor, low alkalinity, soft water Arctic Lake. The lake was weakly stratified during August sampling and well oxygenated with dissolved oxygen concentrations exceeding 10 mg/L at all sites and depths. All water quality parameters and indicators were within federal guidelines for protection of freshwater aquatic life, with the exception of chloride and sodium in bottom waters associated with seawater incursions. The phytoplankton assemblage in Baker Lake was dominated by chrysophyte algae, some species of which can produce compounds that create taste and odor issues (i.e., fishy odor). A fishy odor and taste has been reported by some members of the community (HESL 2017), suggesting that taste- and odor-causing species may be present at high enough concentrations to create a taste issue in Baker Lake.

Saline water at depth in Baker Lake, as observed by Johnson (1965), was most pronounced during the open-water period in 2015 and was less pronounced under ice in the winter of 2016 and the summer of 2017. Periodic saline incursions of marine waters from Chesterfield Inlet in response to tidal cycles, winds, and relative water levels, along with changes in ice cover and freshet-induced mixing of Baker Lake waters, create a dynamic environment of salinity in Baker Lake.

Acknowledgements

We would like to thank Polar Knowledge Canada and the Nunavut General Monitoring Plan for funding, and Jeff Hart of KIA in Baker Lake for assistance with logistics and the sampling program. Data tables and detailed figures were omitted from this manuscript because of space restrictions, but complete technical reports and summaries can be obtained from KIA or Hutchinson Environmental Sciences Ltd.

References

Bengtsson, L. 1996. Mixing in ice-covered lakes. *Hydrobiologia 322: 91–97.*

Budgell, W.P. 1976. Tidal propagation in Chesterfield Inlet, NWT. Fisheries and Environment Canada, Canada Centre for Inland Waters. Manuscript Report Series No. 3: xiv + 99 pp.

Budgell, W.P. 1982. Spring-neap variation in the vertical stratification of Chesterfield Inlet, Hudson Bay. *Naturaliste Canadien* 109:709–718.

Canadian Council of Ministers of the Environment. 2003. Canadian water quality guidelines for the protection of aquatic life. Available from file:///C:/Users/neil/Downloads/CEQGchemicals.pdf.

Dohler, G.C. 1968. Tides and currents. *In* Science, history, and Hudson Bay, vol. 2, Beals, C.S. and Shenstone, D.A. (eds.), Department of Energy, Mines, and Resources, Ottawa. pp. 824–837.

Georgas, N. 2011. Large seasonal modulation of tides due to ice-cover friction in a midlatitude estuary. *Journal of Physical Oceanography* 42:352–369.

Hadley, K.R., Paterson, A.M., Hall, R.I., and Smol, J.P. 2013. Effects of multiple stressors on lakes in south-central Ontario: 15 years of change in lakewater chemistry and sedimentary diatom assemblages. *Aquatic Sciences* 75 (3):349–360.

Health Canada. 2014. Guidelines for Canadian drinking water quality summary table. Water and Air Quality Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa.

Holm, N.P. and Armstrong, D.E. 1981. Role of nutrient limitation and competition in controlling the populations of *Asterionella formosa* and *Microcystis aeruginosa* in semi-continuous culture. *Limnology and Oceanography* 26:622–634.

Hutchinson Environmental Sciences Ltd. (HESL). 2017. One Voice Year 2. Prepared for the Kivalliq Inuit Association.

Johnson, L. 1965. The salinity of Baker Lake, NWT, Canada. *Journal of the Fisheries Board of Canada* 22:239–241.

Medeiros, A.S., Friel, C.E., Finkelstein, S.A., and Quinlan, R. 2012. A high-resolution multi-proxy record of pronounced recent environmental change at Baker Lake, Nunavut. *Journal of Paleolimnology* 47 (4):661–676.

National Oceanic and Atmospheric Administration. 2011. Tides under the ice: Measuring water levels at Barrow, Alaska, 2008–2010. NOAA Technical Report NOS CO-OPS 062.

Nicholls, K.H. 1995. Chrysophyte blooms in the plankton and neuston of marine and freshwater systems. *In* Chrysophyte algae: Ecology, phylogeny, and development, Sandgren, C.D., Smol, J.P., and Kristiansen, J. (eds.), Cambridge University Press, Cambridge. pp. 181–213.

Solovieva, N., Jones, V., Birks, J.H., Appleby, P., and Nazarova, L. 2008. Diatom responses to 20th century climate warming in lakes from the northern Urals, Russia. Palaeogeography, *Palaeoclimatology, Palaeoecology* 259 (2–3):96–106.

Stewart, D.B. and Lockhart, W.L. 2005. An overview of the Hudson Bay marine ecosystem. Canadian Technical Report of Fisheries and Aquatic Sciences. 2586: vi + 487 pp.

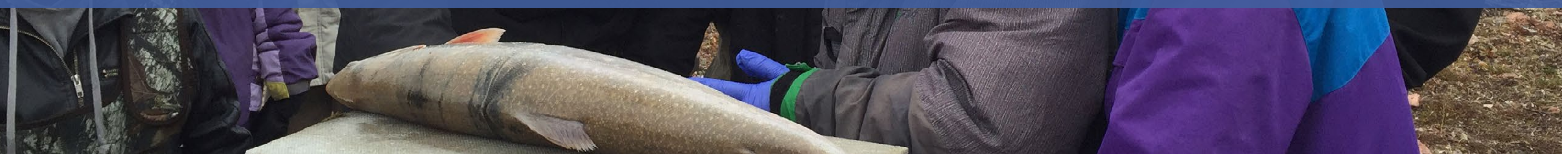
Watson, S.B., Satchwill, T., Dixon, E., and McCauley, E. 2001. Under-ice blooms and source-water odour in a nutrient-poor reservoir: Biological, ecological, and applied perspectives. *Freshwater Biology* 46:1–15.

Wilkinson, A.N., Zeeb, B.A., Smol, J.P., and Douglas, M.S.V. 1996. Chrysophyte stomatocyst assemblages associated with periphytic High Arctic pond environments. *Nordic Journal of Botany* 16:95–112.

Zeeb, B.A. and Smol, J.P. 2001. Chrysophyte scales and cysts In Tracking environmental change using lake sediments, vol. 3, Terrestrial, algal, and siliceous indicators, Smol, J.P, Birks, H.J.B., and Last, W.M. (eds.), Kluwer Academic Publishers, Dordrecht, the Netherlands.

LEARNING TOGETHER:

Science and Inuit Qaujimajatuqangit join forces to better understand iqalukpiit / Arctic char in the Kitikmeot region



Natasha Thorpe[1*], Jean-Sébastien Moore[2], and the Ekaluktutiak Hunters and Trappers Organization

[1] *Thorpe Consulting Services, North Vancouver, British Columbia, Canada*

[2] *Département de biologie, Centre d'études nordiques, and Ressources Aquatiques Québec, Université Laval, Québec, Canada*

* *nt.thorpe@gmail.com*

Abstract

Arctic char (iqalukpiit) have been central to the identity, livelihood, and culture of the Inuit of Ekaluktutiak/Iqaluktuuttiaq[1] (Cambridge Bay) for thousands of years. Since the 1960s, this important subsistence source has also supported commercial fisheries, thereby providing income and opportunity to many in the community. In 2013, a collaboration between Fisheries and Oceans Canada and the Ocean Tracking Network was initiated to use acoustic telemetry to track the migrations of Arctic char in both the marine and fresh waters of the region. Input from local Inuit was key to the success of this major scientific initiative, and prompted a POLAR-funded collaborative effort with the Ekaluktutiak Hunters and Trappers Organization (EHTO) to document the Inuit Qaujimajatuqangit (IQ), traditional knowledge, of Arctic char. For this project, local youth were trained to conduct semidirected ethnocartographic interviews to document the IQ of nine individuals of the community. Interview findings then guided the scientific work and contributed to an IQ database managed by the EHTO. This initiative culminated in an Elder-youth knowledge exchange camp for a week in August 2016. It took place beside the Ekalluk River at Iqaluktuuq, an archaeological site used for over 4,000 years. During this camp, Elders and youth from the community, as well as fisheries biologists and social scientists, exchanged their knowledge and stories related to iqalukpiit. Overall, the community-led project contributed to the recording and preservation of IQ through reports and a video documentary, built capacity and bridges between generations and disciplines, provided an opportunity for healing on the land, and allowed new insights into iqalukpiit, all of which are instrumental in managing a redefined relationship between people and fish in a changing Arctic.

Introduction

Iqalukpiit (Arctic char; *Salvelinus alpinus*) is one of the most harvested species in Inuit Nunangat (Priest and Usher 2004; Lemire et al. 2015), and it has supported Inuit food security for thousands of years (Balikci 1980; Thompson 2005). Given the importance of Arctic char fisheries, sustainable management in the face of a rapidly changing Arctic will require the best available evidence from multiple perspectives.

1 There are two orthography systems for Inuinnaqtun, a dialect of Inuktitut used in the Kitikmeot Region. In this paper, we use the new system, in keeping with Government of Nunavut practice.

Suggested citation:

Thorpe, N., Moore J.-S., and the Ekaluktutiak Hunters and Trappers Organization. Learning together: Science and Inuit Qaujimajatuqangit combine to better understand Iqalukpiit/Arctic Char in the Kitikmeot region. Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 84–91. DOI: 10.35298/pkc.2018.11*

Arctic char exhibit a complex migratory strategy shaped by environmental factors, a cycle long observed and planned around by Inuit. Most of the Arctic char populations targeted for harvest are anadromous, meaning that they migrate between fresh water and the ocean (Johnson 1980). Inuit continue to camp across Nunavut at well-known rivers where these dependable fisheries run. In the past, accurate predictions of migratory cycles were required for survival, whereas today, harvesting iqalukpiit contributes to the ongoing connection between Inuit and country food in a time of great cultural change.

Arctic char in the Cambridge Bay region

Iqalukpiit has been central to the life of the Tuniit and Inuit at Iqaluktuuq, an important fishing site near Cambridge Bay, for thousands of years (Friesen 2002, 2009; Pelly 2002; Friesen and Keith 2006; Norman and Friesen 2010), and subsistence harvesting continues to be an important part of the economy for many families that take advantage of abundant and readily available Arctic char nearby (Kristofferson and Berkes 2005; Avalak 2016; J. Ekpakohak 2016; R. Ekpakohak 2016).

> *[In the 1960s] …there were maybe four families living there, but in the summertime, it was just like a tent city over in Iqlauktuuq because there was a lot of people that went from here [Iqaluktuuttiaq] to Iqaluktuuq to go fishing for themselves or to commercial fish. It was good in those days, there was a lot of fish. When people gathered over in Iqaluktuuq, it was a fun time. (R. Ekpakohak, May 4, 2016)*

Since the 1960s, the rivers of the region have also supported the most important Arctic char commercial fishery to operate in Canada (Day and Harris 2013). With commercial landings averaging more than 41,000 kg per year, this economic activity provides an income to many fishers as well as to numerous part-time and full-time workers in the fish processing plant operating in Cambridge Bay. While subsistence harvests are exclusively managed by Inuit, as per the Nunavut Land Claims Agreement (1993), Fisheries and Oceans Canada (DFO) has joint jurisdiction over the co-management of commercial fisheries (Kristofferson and Berkes 2005). Consequently, scientific data on harvests and biological parameters of Arctic char have been collected more or less continuously since the inception of the fisheries, and there is a long history of scientists collaborating with local experts in the region (e.g., Kristofferson and Berkes 2005; Day and Harris 2013; Knopp 2017).

Context of the project

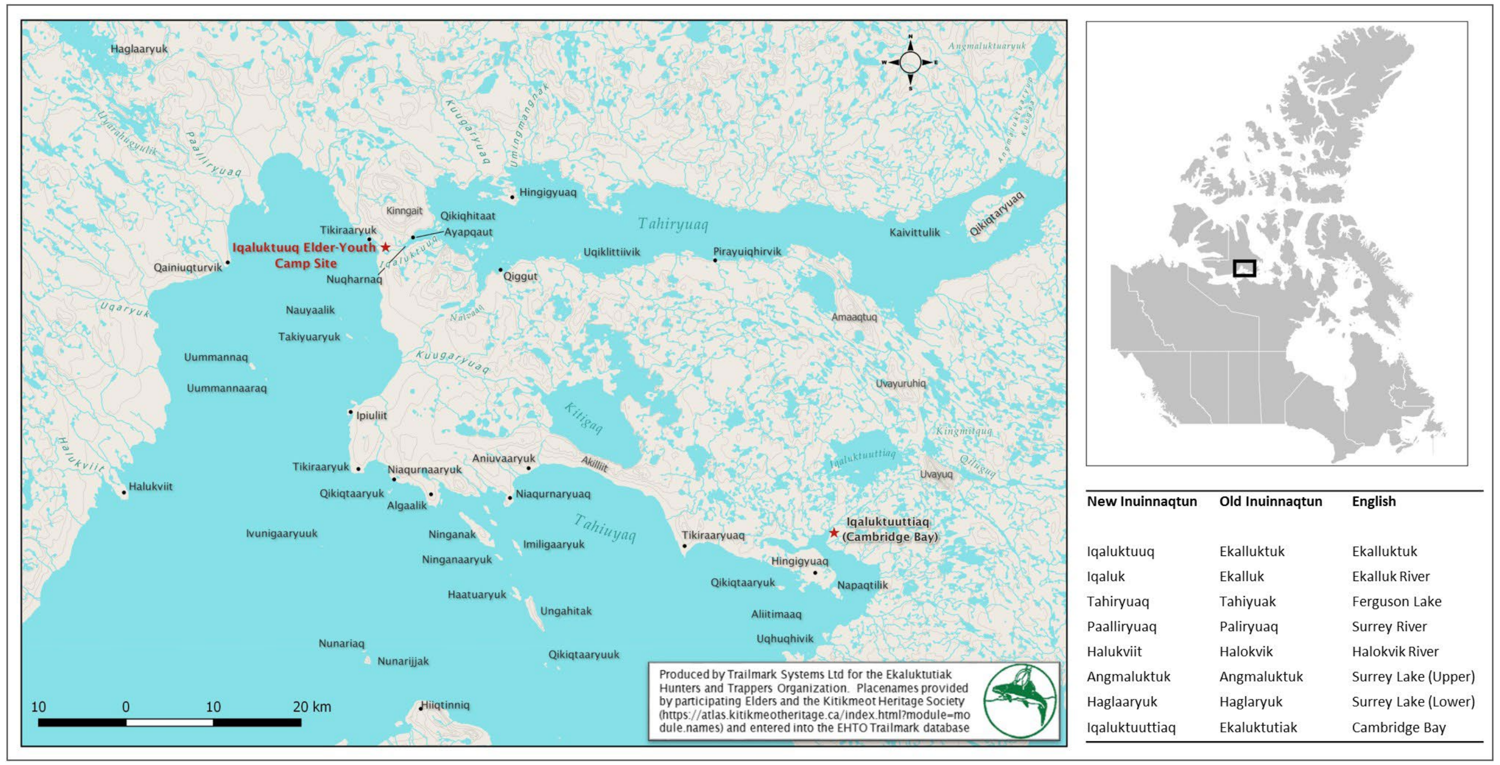
In 2013, the Ocean Tracking Network (OTN) partnered with DFO to initiate a scientific project to study the marine migrations of anadromous Arctic char in the region. The study involved the use of acoustic telemetry, a technology that tracks movements of fish that are surgically equipped with acoustic transmitters, with the help of moored acoustic receivers deployed throughout the region (see Moore et al. 2016 for details of the methodology). This project not only received the approval of the community following pre-project engagement, but also benefited greatly from the input of key resource users through informal meetings both before and during the work. Most notably, input from local experts helped alleviate one of the major limitations of acoustic telemetry approaches: the use of fixed acoustic receivers to describe movements. Indeed, the movement of tagged fish can only be inferred from their detection on receivers that are deployed at specific locations. If fish frequent an area but no receivers are deployed at that location, inferences will be misleading. The OTN-DFO study, therefore, greatly benefited from insights by local experts who suggested the importance of several areas that were not included in the initial study design. As knowledge exchanges continued, it became clear that the scientific project, while providing important insights into Arctic char behaviour, was only telling half the story. Interactions between researchers and community members became the impetus for a community-led IQ project to better understand iqalukpiit from the perspective of Iqaluktuurmiut, the people of Iqaluktuuq.

Methodology and approach

The project took place in three phases that balanced researcher- and community-driven questions, objectives, and approaches. Throughout all phases, many project elements were unplanned and ultimately adapted in response to community input. Methods, results, and reflections are detailed in EHTO and Trailmark (2017).

Phase 1: Scoping

While researchers provided the initial impetus to develop this project, the initiative only proceeded after



New Inuinnaqtun	Old Inuinnaqtun	English
Iqaluktuuq	Ekalluktuk	Ekalluktuk
Iqaluk	Ekalluk	Ekalluk River
Tahiryuaq	Tahiyuak	Ferguson Lake
Paalliryuaq	Paliryuaq	Surrey River
Halukviit	Halokvik	Halokvik River
Angmaluktuk	Angmaluktuk	Surrey Lake (Upper)
Haglaaryuk	Haglaryuk	Surrey Lake (Lower)
Iqaluktuuttiaq	Ekaluktutiak	Cambridge Bay

Figure 1: Map of the Cambridge Bay region on southern Victoria Island, Nunavut, Canada. The location of the Elder-Youth Camp, Iqaluktuuq, is shown by a star.

community engagement took place and direction was given. A scoping phase was initiated by N. Thorpe in April 2015 through in-person meetings with the EHTO and community members (particularly Elders) to gauge interest and discuss what people wished to achieve. Acting on the strong support received for the initiative, monthly discussions with the EHTO followed (via phone or email) for the remainder of 2015 and 2016, with a focus on developing specific project goals, objectives, desired outcomes, logistics, and securing funding.

Phase 2: Training and interviews

The EHTO selected two community researchers to participate in a five-day training course focused on interviewing techniques, mapping, and database management. In May 2016, training continued as the researchers interviewed nine IQ experts with an interpreter present when needed. These semidirected and ethnocartographic interviews focused on iqalukpiit. These interviews were audio recorded and reviewed within an online map-based database developed by Trailmark Systems Ltd. Community researchers transcribed interview recordings and validated them with the interviewees shortly thereafter. Interview results not only populated the EHTO database, but also informed the Elder-Youth Camp and factored into the methods and findings of the project.

Phase 3: The Elder-Youth Camp

During the scoping phase of the project, one of the major community goals expressed was to have an opportunity for hands-on learning and knowledge-sharing through an Elder-youth camp. For this event, the EHTO chose a traditional site named Iqaluktuuq, meaning “a place of many fish” in Inuinnaqtun. It is no wonder that this site has been used for over 4,000 years, given that the Arctic char population at the Ekalluk River is the most abundant (McGowan 1990) and supports the most important commercial fishing quota in the region (Day and Harris 2013). Several families called this area home until a combination of family tragedy and government policy meant they left for nearby communities in the late 1960s and early 1970s (TRC 2015).

The camp was designed to supplement the interview phase by providing an opportunity to “ground-truth” the findings and have Elders share IQ through demonstration and practical instruction in a hands-on environment, thereby providing youth with the opportunity to learn by doing. The main focus was to promote meaningful

Figure 2: The Iqaluktuuq Elder-Youth Camp. (a) The camp was located at the mouth of the Iqaluktuuq (Ekalluk) River, where it empties into Wellington Bay. (b) Participants process and prepare the day’s catch.

interactions among youth and Elders, where the outdoor environment and events prompted memories and instructive stories to be freely recalled and shared, allowing key insights contributed during the interviews to be directly applied in the field. In addition, both youth and Elders engaged with a fisheries scientist who demonstrated techniques to collect data on the health of fish stocks (e.g., how to measure and weigh fish, how to extract otoliths and read the age of the fish).

Results: Learning together

While a key goal of the interviews and the Elder-Youth Camp was to document detailed understandings of Arctic char, a more significant objective revealed itself in Phase 3 once the group was on the land: Iqaluktuurmiut experienced a profound and emotional homecoming upon arriving at Iqaluktuuq, such that discussion about fish became secondary. Not only did coming to this important area trigger powerful memories for several Elders, but there was also a strong realization that this way of living — subsisting off the land as the Inuit way — is increasingly challenging today, given the many competing pressures. Accordingly and respectfully, discussion about iqalukpiit became less important than the healing process of simply “coming home” and being together on the land. This critical aspect of the research, with implications for stand-alone IQ projects as well as collaborative research, was elaborated in EHTO and Trailmark (2017). In the following discussion of results, we present one example of collaborative learnings.

Example of insights gained from learning together

It is beyond the scope of this paper to provide an exhaustive list of insights gained from both scientific approaches and IQ throughout all phases of the project. Here we present an example where combining IQ and science provided new knowledge that would have been impossible to realize through one approach alone. Several interviewees mentioned that Arctic char tended to stay close to shore early after ice breakup, but moved farther offshore later in the season. Local experts hypothesized that fish were either tracking prey or avoiding warm waters.

> *Every year we get lots of Arctic char out at the Gravel Pit, but as soon as the shore gets warm, there are no char. We see big schools of char way out. It makes me curious; maybe the char don’t like that warm water along the coast. Or maybe their feed is gone from along the coast because of the warmth. I have no idea. If our temperatures are going to keep rising like they have for the last 30 years, what is going to happen to our char? I want to know. (Anonymous, April 27, 2015)[2]*

2 Public meeting with EHTO, Elders, and N. Thorpe; Arctic Islands Lodge Boardroom; Cambridge Bay. The authors would have preferred to give credit to each speaker that contributed insights during the project meetings that were held in advance of the research. However, given that participants did not sign informed consent forms, this quotation is provided from meeting notes, which provide key insights without acknowledging sources.

Figure 3: The Elder-Youth Camp was designed to foster meaningful interactions among Elders, youth, and researchers. (a) M. Avalak teaches A. Omilgoetok how to filet a fish with an ulu. (b) J.-S. Moore teaches basic fisheries science techniques to N. Ekapkohalak and the other camp participants.

This insight prompted scientists to look at their telemetry data differently and observe that Arctic char swam at increasingly greater depths as the summer progressed (Harris: pers. comm. 2018). Sensors contained in some of the tags also allowed measurement of the body temperature of tagged fish (fish are ectotherms, so body temperature closely matches water temperature) and showed that their temperature remained constant throughout the summer, thereby providing corroborating evidence that the use of deeper waters may be linked to temperature regulation (Harris pers. comm. 2018). Here, a crucial observation by a local expert made scientists explore their data differently, which led them to insights into the mechanisms driving the observed behaviour (here, temperature regulation), thus providing an answer to a question asked by this local expert. It is therefore a strong example of synergies that can be created from the iterative sharing of information from different perspectives that are placed on equal footing.

Conclusion

In this time of rapid environmental and social change, co-management in Inuit Nunagat requires innovative approaches to collaboration, where IQ and scientific knowledge can come together to provide enhanced understandings of land and resources. Indeed, such collaboration may contribute not only to better understandings, but also to reconciliation and healing between disciplines, generations, and peoples.

Collaboration between the EHTO, DFO, and OTN throughout this project demonstrated that insights can come from comparing knowledge acquired through different perspectives. Through our work, participants and researchers alike showed that learnings from both ways of knowing could combine to provide a more comprehensive understanding of Arctic char in Iqaluktuuq. Through IQ, Elders taught youth about Arctic char. Moreover, this led to some enlightening observations on various aspects of iqalukpiit biology, which in many cases, will help scientists to frame hypotheses that can lead to new understandings or alter their research methods. Reciprocally, the scientific data gathered in response to IQ observations can enrich existing knowledge through the use of technology not previously available to community members and resource users.

Perhaps the greatest learning, with application and relevance across the north, is that all success depends on the willingness of outsider researchers to lose some control of their research and relinquish some key objectives in the face of a more relevant imperative. In our experience, this meant that just as iqalukpiit return to their natal lakes from the ocean, Iqaluktuurmiut similarly return home to Iqaluktuuq, where memoryscapes and ties to both ancestors and history abound. If IQ holders and western scientists are going to collaborate meaningfully in Nunavut, outsiders and scientists must continually adapt to integrated community research, even when this means their research goals may float downstream.

POLAR KNOWLEDGE Aqhaliat

Community considerations

As an IQ initiative, the work presented in this project was grounded in strong involvement from community members who contributed to all aspects of the work. The project is relevant for the communities in the north and in other parts of Canada as an example of how science and IQ, or traditional knowledge, can work hand in hand to generate novel insights on species of importance.

Acknowledgements

This project would not have been possible without the generous and tireless efforts of the Elders who freely shared their expertise and support. The vision, dedication, and hard work of the Ekaluktutiak Hunters and Trappers Organization board and staff members — too many to name — ensured success at every turn. Special thanks are extended to aRTIeSS Collective for training youth and producing the documentary video Iqaluktuuq (https://vimeo.com/211587576) and to Trailmark Systems Ltd. for providing database management support and reporting. In addition to core funding from Polar Knowledge Canada, support was provided by the Environment Canada Aboriginal Fund for Species at Risk, Fisheries and Oceans Canada, Kitikmeot Inuit Association, Nunavut Wildlife Management Board, and Oceans North Canada.

References

Avalak, M. Elder. 2016. Interviewed with J. Ekpakohak. Interviewed by J.Akoluk, C. Kapolak, and N. Thorpe. May 5, 2016. Cambridge Bay, NU.

Balikci, A. 1980. Charr fishing among the Arviligjuarmiut. *In* Charrs: Salmonid fishes of the genus Salvelinus. Balon, E.K. (ed.), Dr. W. Junk Publishers, The Hague. pp. 7–9.

Day, A. C. and Harris, L.N. 2013. Information to support an updated stock status of commercially harvested Arctic char (Salvelinus alpinus) in the Cambridge Bay region of Nunavut, 1960–2009. DFO Canadian Science Advisory Secretariat Research Document 2013-068. v + 30 pp. Available from http://waves-vagues.dfo-mpo.gc.ca/Library/350263.pdf.

Ekaluktutiak Hunters and Trappers Organization and Trailmark Systems Ltd. (EHTO and Trailmark). 2017. Inuit qaujimajatuqangit of iqalukpiit near Iqaluktuuq: Bringing together Elders, fishers, and youth to understand Arctic char. Cambridge Bay, NU. 39 pp.

Ekpakohak, J. Elder. 2016. Interviewed with M. Avalak. Interviewed by J. Akoluk, C. Kapolak, and N.Thorpe. May 5, 2016. Cambridge Bay, NU.

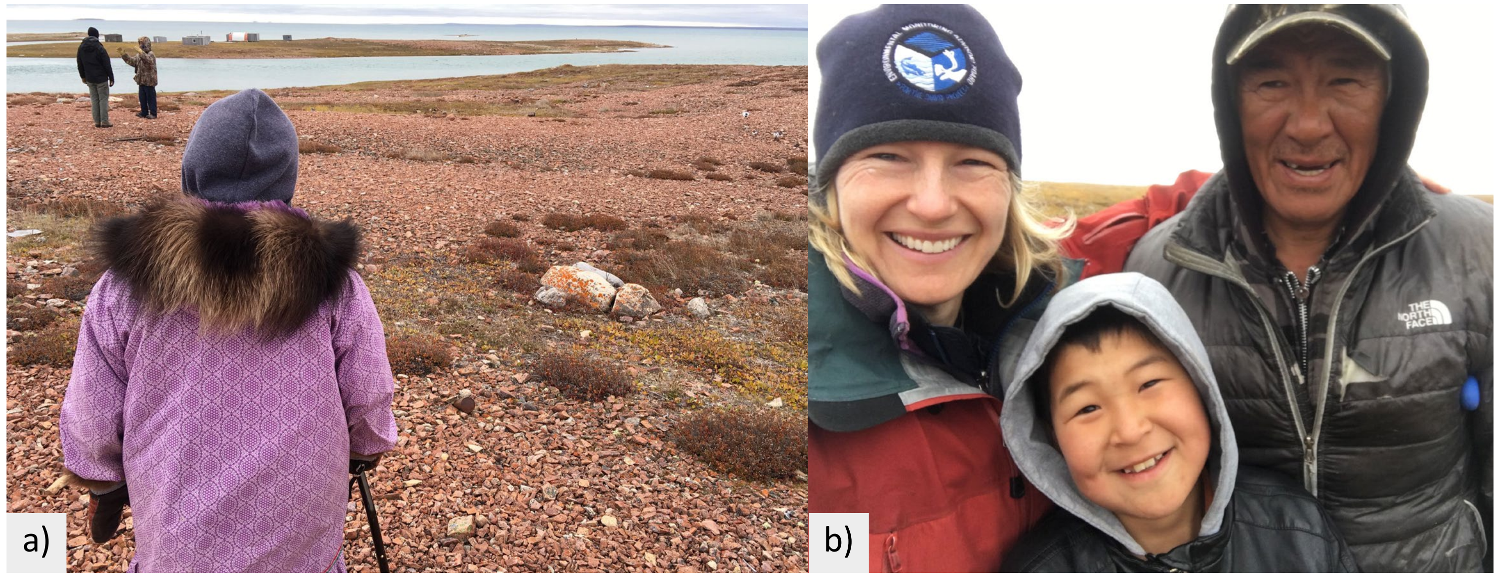


Figure 4: While the initial focus of the camp was on iqalukpiit, the human and social aspects of coming home, healing, and experiencing meaningful interactions became central. (a) M. Avalak returns to where she grew up after nearly 50 years away. (b) N. Thorpe, A. Anavilok, and G. Angohiatok enjoy a selfie together.

Ekpakohak, R. Elder. 2016. Interviewed by J. Akoluk, C. Kapolak, and N. Thorpe. May 4, 2016. Cambridge Bay, NU.

Friesen, T. M. 2009. The last supper: Late Dorset economic change at Iqaluktuuq, Victoria Island. *In* The northern world AD 900–1400. Maschner, H., Mason, O., and McGhee, R. (eds.), University of Utah Press, Salt Lake City. pp. 235–248.

Friesen, T.M. 2002. Analogues at Iqaluktuuq: The social context of archaeological inference in Nunavut, Arctic Canada. *World Archaeology* 34 (2):330–345. doi:10.1080/00438240 22000007134. Available from https://docs.wixstatic.com/ugd/56a2ca_7095e144f9264beda0d1586226159057.pdf).

Friesen, T.M. and Keith, D. 2006. Iqaluktuurmiutat: Life at Iqaluktuuq. Kitikmeot Heritage Society. Artisan Press, Yellowknife. Available from https://docs.wixstatic.com/ugd/56a2ca_69d1791416474d67b6ad8c7f5914cdf7.pdf.

Harris, L. pers. comm. 2018. Fisheries Biologist, Fisheries and Oceans Canada. March 2, 2018. Email to J.-S. Moore.

Johnson, L. 1980. The Arctic charr, Salvelinus alpinus. *In* Charrs: Salmonid fishes of the genus Salvelinus. Balon, E.K. (ed.), Dr. W. Junk Publishers, The Hague. pp. 15–98.

Knopp, J.A. 2017. Linking Inuit and scientific knowledge and observations to better understand Arctic char, Salvelinus alpinus (L.), community monitoring. Ph.D. dissertation, Trent University, Peterborough, Ont. 316 pp.

Kristofferson, A.H., McGowan, D.K., and Carder, G.W. 1984. Management of the commercial fishery for anadromous Arctic charr in the Cambridge Bay area, Northwest Territories, Canada. *In* Biology of the Arctic charr: Proceedings of the international symposium on Arctic charr. Johnson, L. and Burns, B. (eds.), University of Manitoba Press, Winnipeg.

Kristofferson, A.H. and Berkes, F. 2005. Adaptive co-management of Arctic char in Nunavut territory. *In* Breaking ice: Renewable resource and ocean management in Canada's North. Berkes, F., Huebert, R., Fast, H., Manseau, M., and Diduck, A. (eds.), University of Calgary Press. pp. 249–268. Available from http://umanitoba.ca/institutes/natural_resources/canadaresearchchair/Kristofferson%20&%20Berkes%20Chap%2012.pdf.

Lemire, M., Kwan, M., Laouan-Sidi A.E., Muckle, G., Pirkle, C., Ayotte P, and Dewailly, E. 2015. Local country food sources of methylmercury, selenium, and omega-3 fatty acids in Nunavik, northern Quebec. *Science of the Total Environment* 509–510:248–59. ISSN:0048-9697. Available from https://www.sciencedirect.com/science/article/pii/S0048969714011395?via%3Dihub.

McGowan, D. K. 1990. Enumeration and biological data from the upstream migration of Arctic charr, Salvelinus alpinus (L.), in the Cambridge Bay area, Northwest Territories, 1979–1983. Canadian Data Report of Fisheries and Aquatic Sciences 811: iv + 27 pp. Available from http://www.dfo-mpo.gc.ca/Library/116586.pdf).

Moore, J.-S., Harris, L.N., Kessel, S., Bernatchez, L., Tallman, R.F., and Fisk, A.T. 2016. Preference for near-shore and estuarine habitats in anadromous Arctic char (*Salvelinus alpinus*) from the Canadian High Arctic (Victoria Island, NU) revealed by acoustic telemetry. *Canadian Journal of Fisheries and Aquatic Sciences* 73 (9):1434–1445. Available from https://www.bio.ulaval.ca/louisbernatchez/pdf/(370)%20Moore_CanadianJFishAquatSci_2016.pdf).

Norman, L. and Friesen, T.M. 2010. Thule fishing revisited: The economic importance of fish at the Pembroke and Bell sites, Victoria Island, Nunavut. Geografisk Tidsskrift — *Danish Journal of Geography* 110 (2):261–278. Available from http://www.academia.edu/1862792/Thule_Fishing_Revisited_The_Economic_Importance_of_Fish_at_the_Pembroke_and_Bell_Sites_Victoria_Island_Nunavut.

Pelly, D. 2002. Iqaluktuuq: Inuit Elders and archaeologists unravel our past. *Above and Beyond* March/April 2002, pp. 43–51. Available from http://www.davidpelly.com/Iqaluktuuq.pdf.

Priest, H. and Usher, P. 2004. The Nunavut wildlife harvest study. Nunavut Wildlife Management Board, Iqaluit, NU. 810 pp. Available from https://www.nwmb.com/iku/publications/harvest-study/1824-156-nwhs-report-2004-156-0003/file.

Roux, M.J., Tallman, R.F., and Lewis, C.W. 2011. Small-scale Arctic charr, Salvelinus alpinus, fisheries in Canada's Nunavut: Management challenges and options. *Journal of Fish Biology* 79:1625–1647. Available from https://onlinelibrary.wiley.com/doi/full/10.1111/j.1095-8649.2011.03092.x.

Thompson, S. 2005. Sustainability and vulnerability: Aboriginal Arctic food security in a toxic world; *In* Breaking ice: Renewable resource and ocean management in Canada's North, chap. 3. Berkes, F., Huebert, R., Fast, H., Manseau, M., and Diduck, A. (eds.), University of Calgary Press. pp. 47–69. Available from https://umanitoba.ca/institutes/natural_resources/canadaresearchchair/Thompson%20Chap%203.pdf).

Truth and Reconciliation Commission (TRC). 2015. Canada's residential schools: The Inuit and northern experience; The final report of the Truth and Reconciliation Commission of Canada, volume 2. McGill-Queen's University Press. 187 pp. Available from http://www.myrobust.com/websites/trcinstitution/File/Reports/Volume_2_Inuit_and_Northern_English_Web.pdf.

INTRODUCTION TO TRADITIONAL KNOWLEDGE STUDIES IN SUPPORT OF GEOSCIENCE TOOLS FOR ASSESSMENT OF METAL MINING IN NORTHERN CANADA

Jennifer M. Galloway[1,*] and R. Timothy Patterson[2]

[1] *Geological Survey of Canada Calgary / Commission géologique du Canada, Calgary, Alberta, Canada*

[2] *Department of Earth Sciences and Ottawa-Carleton Geoscience Centre, Carleton University, Ottawa, Ontario, Canada*

* *Jennifer.Galloway@canada.ca*

The Geoscience Tools for Environmental Assessment Project is being co-led by the Geological Survey of Canada and Carleton University, in collaboration with the Government of the Northwest Territories Cumulative Impact Monitoring Program, the Northwest Territories Geological Survey, Crown-Indigenous Relations and Northern Affairs Canada, Environment and Climate Change Canada, the Canadian Museum of Nature, Queen's University, the University of Leeds, Seabridge Gold, TerraX Minerals Ltd., the Yellowknives Dene First Nation, the North Slave Métis Alliance, the Tłı̨chǫ Government, the Tłı̨chǫ Research and Training Institute, and Hadlari Consulting Ltd. The study area is the Slave Geological Province, with a focus on the areas around Yellowknife and Courageous Lake, Northwest Territories.

Abstract

We applied a multidisciplinary research methodology to reconstruct variations in climate, geochemistry, permafrost, and ecology over the past 1,000 years along a north-south transect in the Slave Geological Province in order to assess the cumulative effects of natural and human-driven change on the transport and fate of metals/metalloids and on the health of regional ecosystems in areas of high resource potential in northern Canada. The study focussed on Yellowknife and Courageous Lake, two areas with known gold resources and contamination from historical mining. Through collection and analyses of cores from lake sediments and permafrost peatlands, combined with spatial data, Traditional Knowledge, and Inuit Qaujimajatuqangit, the impact of climate change and land disturbance on metal/metalloid flux into aquatic systems was assessed. This contribution serves as an introduction to the project, with a focus on the traditional knowledge developed as part of this research.

Traditional knowledge studies were conducted by several project partners: the North Slave Métis Alliance, the Yellowknives Dene First Nation, the Tłı̨chǫ Research and Training Institute, and Hadlari Consulting Ltd., an Inuit-owned-and-operated business. The studies provide insight into past climate and land-use changes not discernible from paleoecological records alone. Specific information on seasonality, ice quality, lake water levels, pre-industrial environmental conditions, traditional land use, spatial extent of contamination associated with legacy mining, and impact of climate change on cultural land use are some examples of the kinds of information derived from the traditional knowledge studies. The integrated, multidisciplinary approach employed in this research project highlights the utility of combining different ways of knowing to generate a knowledge assemblage that incorporates human contextual information and develops a deeper understanding of the cumulative impacts of legacy mining and climate change in northern Canada.

Suggested citation:

Galloway, J.M. and Patterson, R.T. 2018. Introduction to traditional knowledge studies in support of geoscience tools for assessment of metal mining in northern Canada. Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 92–98. DOI: 10.35298/pkc.2018.12*

Introduction

Geoscience Tools for Environmental Risk Assessment of Metal Mining was a three-year (2015–2018) project undertaken by the Geological Survey of Canada (GSC) and Carleton University, and funded by Polar Knowledge Canada (Project #1516-149) and the GSC. The project, co-led by Jennifer Galloway (GSC) and Timothy Patterson (Carleton University), was a collaborative effort to study the impact of climate change on the transport and fate of arsenic at two sites contaminated by legacy mining and mineral processing: Giant Mine, Yellowknife, and Tundra Mine in the Courageous Lake area(Fig. 1; Galloway et al. 2012, 2015, 2017; Palmer et al. 2015). This information may be used to assess the efficacy of remediation and establish benchmarks against which potential impacts of future resource development, land use, and climate change can be determined and regulated as necessary.

Regional pre-mining background and baseline levels of arsenic were determined through analyses of lake sediment-water interface samples and surfacewater samples from 100 lakes in the Yellowknife area (Galloway et al. 2012, 2017; Palmer et al. 2015) and an additional ~100 lakes spanning a latitudinal gradient from Hay River to Lac de Gras (Fig. 1; Galloway et al. 2015). The second phase of the research, which is ongoing, is focussed on mechanisms involved in the transport and fate of arsenic in aquatic environments (alloway et al. 2017) and proxy-based reconstruction of climate over the past ~1,000 years through analyses of lake sediment and peat cores. This hind-casting approach offers the opportunity to further evaluate the hypothesis that climate mediates chemical change, using studies of past periods of warmth (e.g., the Holocene Hypsithermal and the Medieval Warm Period) as analogues for the twenty-first century and future warming.

Traditional Knowledge (TK) and Inuit Quajimajatuqangit (IQ) represent important sources of information on past climate and pre-industrial environments of the study regions. In collaboration with project partners, the North Slave Métis Alliance (NSMA), the Tłı̨chǫ Research and Training Institute (TRTI), the Yellowknives Dene First Nation (YKDFN), and Hadlari Consulting Ltd., specific insight on past climate changes is expected to provide a more comprehensive understanding of past environmental conditions than could be derived by using western science alone. The study generated by the NSMA is included as part of this volume; the other reports may be published elsewhere in the future.

Traditional knowledge

Traditional knowledge (TK) can be described as culturally relevant information passed from generation to generation, which forms part of a people's cultural identity. A commonly used definition of traditional ecological knowledge (TEK), a subset of TK, is "a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, and [it is] about the relationship of living beings (including humans) with one another and with their environment" (Berkes 1999). Traditional Knowledge or IQ, comprises holistic knowledge systems; knowledge cannot be compartmentalized or separated from the

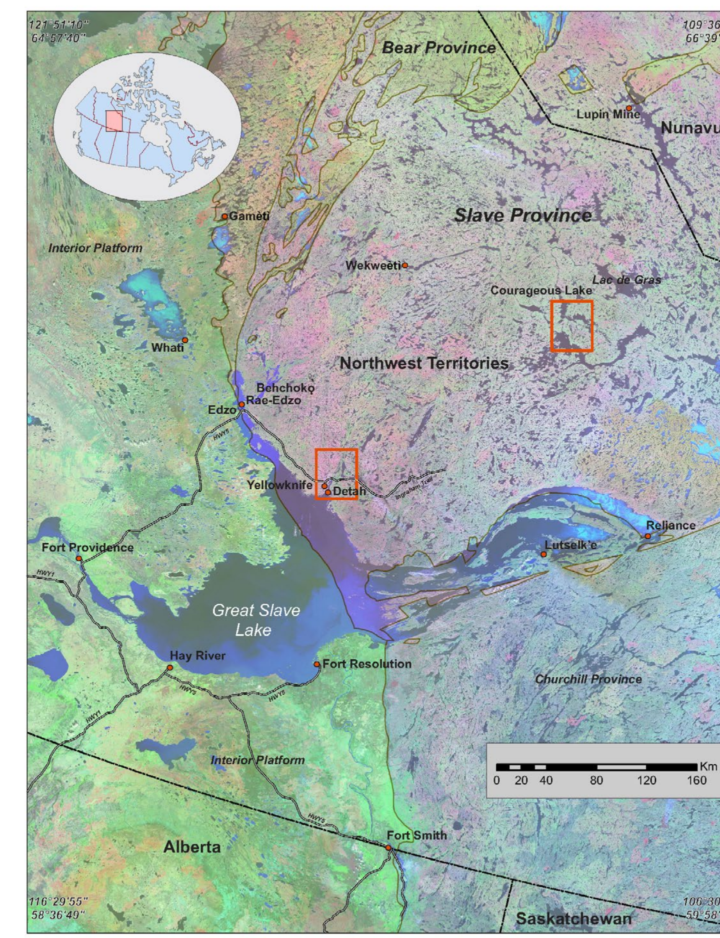


Figure 1: Map of the central Northwest Territories showing the location of the study areas.

Table 1: Some characteristics of traditional knowledge and western science knowledge systems (after Berneshawi 1997; Moller et al. 2004).

	Traditional Knowledge	Western Scientific Knowledge
Dominant mode of thinking	Intuitive, holistic, "interpretation of how the World works from a particular cultural perspective"[a]	Analytical, segmented, specialized, compartmentalized
Communication and learning	Oral in some cases[b,c] observational, story-telling[c-f]	Literate, experimental
Time scale	Synchronic; tends to be long time periods in a specific area; offers depth of experience in a local, culture-specific context[g]	Diachronic; tends to be short-term data over large areas; offers broad context beyond local level[g]
Characteristics	Subjective, spiritual, ethical, moral in some cases	Reductionist, objective,
Skewness	Focus on extremes[h]	Focus on averages
Data creation and transmission	Inclusive, generational, "transferred from generation to generation through daily social and cultural events"[i]	Selective
Prediction abilities	Qualitative	Quantitative, in some cases
Type of explanation	Spiritual in some cases, analogy[d]	Hypotheses, theories, laws
Knowledge management systems	Long-term, decentralized, consensus-based	Centralized, regulated
Assessment of uncertainty	Not explicit[h]	Emphasized
Assessment of authority	Reliability or credibility of knowledge holder determined based on life experience and reputation for holding sound knowledge about a topic by community members; community review	Peer review and associated metrics, determined by scientific community
Similarities	Both improve our understanding of the World and are based on repeated processes of observation, inference, verification, and prediction[j,k]	
	Both are dynamic; new knowledge is incorporated and integrated with information that cannot necessarily be understood in isolation[j]	

[a]Snively and Corsiglia (2000, p. 3); [b]Aronowitz, 1998; [c]Ignas, 2004; [d]MacLean and Wason-Ellam, 2006; [e]Mitchell et al., 2008; [f]Sutherland, 2002; [g]Becker and Ghimire (2003); [h]Huntington et al. (2004); [i]Ogawa (1997, p. 586); [j]Menzies and Bulter (2006); [k]Hoaglund (2017)

people who hold it, and in this aspect, TK differs markedly from the western scientific knowledge system. TK systems are, in general, abstract, qualitative, inclusive, intuitive, diachronic, and formed from communal knowledge gained over time through practice and application (Table 1).

There has been growing acknowledgement of the value of inclusion of TK in understanding climate change, natural resource management, environmental assessment, and remediation and reclamation of industrial sites (Usher 2000; Alexander et al. 2011; Sandlos and Keeling 2016; Hoaglund 2017). TK is well suited to be included in land-use planning strategies, as these knowledge systems address needs for holistic and adaptive management of multiple resources and ecosystems (Berkes et al. 2000). TK also offers the potential to identify and

monitor cumulative impacts of climate and land-use change by providing long-term descriptions of climate variability and its effects on ecosystems, as well as human contextual information, which fill knowledge and understanding gaps that western science cannot address (Johannes 1998; Usher 2000; Huntington et al. 2004; Baker and Mutitjulu Community 2009). TK and paleoecological studies are particularly well suited for integration, as knowledge gained from both approaches is typically local to regional in spatial scale but covers a great deal of time (decades to millennia).

An understanding of the differences and similarities of TK and western science knowledge is required for knowledge integration (Bohensky and Maru 2011; Table 1). The means to address the limitations of direct comparison exist. These include weight of evidence for quantitative and qualitative information (Good 1991; Chapman 2007; Suter and Cormier 2011) and Bayesian statistically-based metrics (Good 1991).

Results and discussion

TK studies to address the research theme and knowledge gaps identified by each community were developed and led by project partners, the NSMA, TRTI, YKDFN, and Hadlari Consulting Ltd. A brief summary of the report generated by the NSMA and the TRTI is provided here.

North Slave Métis Alliance

Continual Change and Gradual Warming: A Summary of the North Slave Métis Alliance's Recorded Cultural Knowledge on Climate and Environmental Change

North Slave Métis Alliance members are keepers of detailed, quantitative information on past climate, and this community reviewed publicly available and culturally relevant literature, which included Hudson's Bay Company journals (e.g., journals from Old Fort Rae covering 1888 to 1912), Warburton Pike's account of travels to the Barren Grounds (published in 1892), John Franklin's expedition documents (including meteorological journals covering 1825 to 1827), and Meteorological Council of Great Britain documents (including temperatures recorded by John Rae at Fort Confidence from 1850 to 1851 and W.J.S. Pullen at Fort Simpson from 1849 to 1851). This literature review was combined with a review of numerous secondary sources held within the NSMA's database, NSMA interview transcripts, and NSMA member journals. The report summarizes quantitative information on climate over the past ~200 years and provides specific insight on changes in seasonality, wind strength and direction, water levels, and snow pack, as well as the impact of climate change on land use by NSMA members.

Tłı̨chǫ Research and Training Institute

Everything Seems to Have Changed

TRTI undertook interviews of TK holders in a community-based setting in order to compile information on past climate and document some of the ways that recent climate warming has impacted traditional lake use. Insight into seasonality and hydrology was of particular interest from a paleoclimate perspective, as these important aspects of the climate system are difficult to reconstruct using proxy-based paleoecological study. Tłı̨chǫ TK holders reported an approximate two-week delay in freeze-up of lakes from early / mid-October to early November. In addition, they reported that the duration of freeze-up is no longer abrupt, and now includes several freeze-thaw events that affect the quality of the ice. TK holders also reported precipitation falling as rain prior to ground freeze-up in the fall, which affects spring melt, and more intense and frequent wildfires during the summer season, which are related to rapidly reduced snowpack in the spring. The report also includes some of the cultural implications of twenty-first-century climate change.

Integration of traditional knowledge and western scientific knowledge

The purpose of the larger study, Geoscience Tools for Environmental Risk Assessment of Metal Mining, is to determine if, and how, climate change has, and may, impact the transport and fate of metal/metalloids. This is highly relevant at contaminated sites in northern Canada, where twenty-first-century climate change is expected to profoundly alter biogeochemical cycling. Acquisition of western scientific knowledge through combined micropaleontological and geochemical study of paleoecological archives is ongoing. Paleoclimatological perspectives offered by TK studies will be compared with western science knowledge to produce a knowledge assemblage. It is expected that each way of knowing will provide unique insight into past climate and environmental change, which can be used to better predict future chemical change.

Conclusions

A collaborative research design that included knowledge holders from First Nation, Métis, and Inuit communities; government; industry; and academia demonstrates that complementary ways of knowing can generate insight into climate change, weather, environmental variability, cumulative effects, land-use change, contamination, changes in seasonality, ice quality, wildfires, and spatial extent of contamination. With this approach, new insight in the areas of interest in the Northwest Territories is produced.

Acknowledgements

Funding for this project was provided by the Geological Survey of Canada (Environmental Geoscience Program), Polar Knowledge Canada (Project #1516-149), the Government of the Northwest Territories Cumulative Impact Monitoring Program, and the Northwest Territories Geological Survey (NTGS). The project would not have been possible without substantial in-kind support from Crown-Indigenous Relations and Northern Affairs Canada, Environment and Climate Change Canada, the Canadian Museum of Nature, Queen's University, the University of Leeds, Seabridge Gold, TerraX Minerals Ltd., the Yellowknives Dene First Nation, the North Slave Métis Alliance, the Tłı̨chǫ Government, the Tłı̨chǫ Research and Training Institute, and Hadlari Consulting, Ltd. We thank Douglas Lemay (GSC) for his drafting assistance in the production of Figure 1. We are grateful to Scott Cairns (NTGS) and Keith Dewing (GSC) for their constructive and helpful comments, which greatly improved the manuscript. This article represents Natural Resources Canada (NRCan-RNCan) Contribution Number: 20180128.

References

Aronowitz, S. 1988. Preface to Science as power: Discourse and ideology in modern society. University of Minnesota Press, Minneapolis, MN.

Baker, L.M. and Mutijulu Community. 1992. Comparing two views of the landscape: Aboriginal traditional ecological knowledge and modern scientific knowledge. *Rangeland Journal* 14: 174–187. doi.org./10.1071RJ9920174.

Becker, C.D. and Ghimire, K., 2003. Synergy between traditional ecological knowledge and conservation science supports forest preservation in Ecuador [online]. *Conservation Ecology* 8 (2):1. Available from http://www.consecol.org/vol8/iss1/art1.

Berkes, F. 1999. Scared ecology: Traditional ecological knowledge and resource management. Taylor and Francis Publishing Company, Philadelphia, PA.

Berkes, F., Colding, J., and Folke, C. 2000. Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications* 10:1251–1262.

Berneswahi, S. 1997. Resource management and the Mik'maq nation. *Canadian Journal of Native Studies* 17:115–148.

Bohensky, E.L. and Maru, Y. 2011. Indigenous knowledge, science, and resilience: What have we learned from a decade of international literature on integration? *Ecology and Society* 16:6. doi.org/10.5751/ES-04342-160406.

Chapman P.M. 2007. Traditional ecological knowledge (TEK) and scientific weight of evidence determination. *Marine Pollution Bulletin* 54:1839–40.

Galloway, J.M., Macumber, A., Patterson, R.T., Falck, H., Hadlari, T., and Madsen, E. 2010. Paleoclimatological assessment of the southern Northwest Territories and implications for the long-term viability of the Tibbitt to Contwoyto winter road: Part 1 - core collection. Northwest Territories Geoscience Office, NWT. Open Report 2010-002, 21 pp.

Galloway, J.M., Palmer, M., Jamieson, H.E., Patterson, R.T., Nasser, N.A., Falck, H., Macumber, A.L., Goldsmith, S.A., Sanei, H., Normandeau, P., Hadlari, T., Roe, H.M., Neville, L.A., and Lemay, D. 2015. Geochemistry of lakes across ecozones in the Northwest Territories and implications for the distribution of arsenic in the Yellowknife region: Part 1 - sediments. Geological Survey of Canada. Open File 7908, 50 pp. + appendix, 1.zip file. doi:10.4095/296954.

Galloway, J.M., Swindles, G.T., Jamieson, H.E., Palmer, M., Parsons, M.B., Sanei, H., Macumber, A.L., Patterson, R.T., and Falck, H. 2017. Organic matter control on the distribution of arsenic in lake sediments impacted by ~65 years of gold ore processing in Subarctic Canada. *Science of the Total Environment* 622–623:1668–1679. doi.org/10.1016/j.scitotenv.2017.10.048.

Good I.J. 1991. Weight of evidence and the Bayesian likelihood ratio. *In* The use of statistics in forensics science, Aitken, C.G.G. and Stoney, D. (eds.), CRC Press, Boca Raton, FL. pp. 85–106.

Huntington, H.P. 2000. Using traditional ecological knowledge in science: Methods and applications. *Ecological Applications* 5:1270–1274.

Ignas, V. 2004. Opening doors to the future: Applying local knowledge in curriculum development. *Canadian Journal of Native Education* 28:49–60.

Johannes, R.E. 1998. The case for data-less marine resource management: Examples form tropical nearshore fisheries. *Trends in Ecology and Evolution* v13:243–246. doi.org./10.1016/SO169-5347(98)01384-6.

MacLean, M. and Wason-Ellam, L. 2006. When Aboriginal and Métis teachers use storytelling as an instructional practice. Available from http://www.education.gov.sk.ca/Storytelling [accessed 1 May 2011].

Menzies, C. and Butler, C. 2006. Introduction: Understanding ecological knowledge. *In* Traditional ecological knowledge and natural resources management, Menzies, C. (ed). p. 127.

Mitchell, H., Vizinia, Y., Augustus, C., and Sawyer, J. 2008. Learning Indigenous science from place. University of Saskatchewan, Aboriginal Education Research Centre, Saskatoon, SK.

Moller, H., Berkes, F., Lyver, P.O., and Kislalioglu, M. 2004. Combining science and traditional ecological knowledge: Monitoring populations for co-management [online]. *Ecology and Society* 9:2 Available from http://www.ecologyandsociety.org/vol9/iss3/art2.

North Slave Métis Alliance community members Shiga, S., Evans, P., King, D., and Keats, B. 2017. Continual change and gradual warming: A summary of the North Slave Métis Alliance's recorded cultural knowledge on climate and environmental change. Report prepared for the Geological Survey of Canada's Geoscience Tools for Environmental Assessment of Metal Mining, compiled by Galloway, J.M. and Patterson, R. T. Project Number #1519-149. *Polar Knowledge: Aqhaliat 2018*, Polar Knowledge Canada, p. ##–## [this volume].

Ogawa, M. 1995. Science education in a multiscience perspective. *Science Education* 79:583–593. doi: 10.1002/sce.3730790507.

Palmer, M., Galloway, J.M., Jamieson, H.E., Patterson, R.T., Falck, H., and Kokelj, S.V. 2015. The concentration of arsenic in lake waters of the Yellowknife area 15 years after the end of gold ore processing. Northwest Territories Geological Survey. Open File 2015–16, 29 pp. doi: 10.13140/RG.2.1.2582.5041.

Snively, G. and Corsiglia, J. 1998. Discovering Indigenous science: Implications for science education. *Science Education.* Retrieved October 2010. ERIC database.

Suter, G.W. and Cormier, S.M. 2011. Why and how to combine evidence in environmental assessments: Weighing evidence and building cases. *Science of the Total Environment* 409:1406–1417.

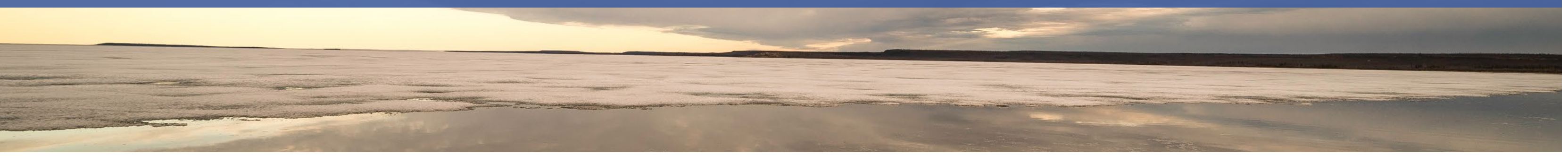
Sutherland, D. 2002. Exploring culture, language, and the perception of the nature of

science. *International Journal of Science Education* 24:1–25. doi:10.1080/09500690110067011.

Usher, P.J. 2000. Traditional ecological knowledge in environmental assessment and management. *Arctic* 53:183–193.

CONTINUAL CHANGE AND GRADUAL WARMING:

A summary of the North Slave Métis Alliance's recorded cultural knowledge on climate and environmental change



North Slave Métis Alliance community members[1*], Shin Shiga[1], Peter Evans[2], Dave King[2], and Beth Keats[2]

[1] North Slave Métis Alliance, Yellowknife, Northwest Territories, Canada

[2] Trailmark Systems Inc., Victoria, British Columbia, Canada

* general@nsma.net

The Geoscience Tools for Environmental Assessment Project is being co-led by the Geological Survey of Canada and Carleton University, in collaboration with the Government of the Northwest Territories Cumulative Impact Monitoring Program, the Northwest Territories Geological Survey, Crown-Indigenous Relations and Northern Affairs Canada, Environment and Climate Change Canada, the Canadian Museum of Nature, Queen's University, University of Leeds, Seabridge Gold, TerraX Minerals Ltd., the Yellowknives Dene First Nation, the North Slave Métis Alliance, the Tlicho Government, the Tłı̨chǫ Research and Training Institute, and Hadlari Consulting, Ltd. The study area comprises the Slave Geological Province, with a focus on the areas around Yellowknife and Courageous Lake, Northwest Territories.

Abstract

Geoscience Tools for Environmental Risk Assessment of Metal Mining was a three-year (2015–2018) project led by the Geological Survey of Canada and Carleton University (Polar Knowledge Canada Project #1516-149). The project was a collaborative effort to study the impact of climate change on the transport and fate of arsenic at two sites contaminated by legacy mining and mineral processing: Giant Mine, near Yellowknife, and Tundra Mine, northeast of Yellowknife in the central NWT. This information may be used to assess the efficacy of remediation and establish benchmarks against which potential impacts of future resource development, land use, and climate change can be determined and regulated as necessary. A hind-casting approach involving both traditional knowledge and western science offers the opportunity to further evaluate the hypothesis that climate can mediate chemical change through studies of past periods of warmth, such as the Holocene Hypsithermal and the Medieval Warm Period, as analogues for twenty-first-century warming and its projected trajectory. Traditional knowledge represents important sources of information on past climate and pre-industrial environments of the study regions. The North Slave Métis Alliance (NSMA) initiated a traditional knowledge study to contribute to a collaborative project led by the Geological Survey of Canada and Carleton University to better understand the role of climate and land-use change on the transport and fate of metal/metalloids in areas of high resource potential and contaminant loads in northern Canada. Métis cultural knowledge linked to climate and associated environmental variability in the Northwest Territories was used to provide long-term climate and environmental data necessary for evaluating records of past geochemical change. Data were extracted from historical interviews conducted with NSMA members and from a selection of primary and secondary literature relevant to Métis historical experience. North Slave Métis Alliance members' cultural knowledge suggests that in addition to variability in weather and corresponding environmental conditions to be anticipated year to year, climate change is producing an overall warming with impacts on seasonality, precipitation, water levels, and ice quality, and as a result, impacts on the health, behaviour, and distribution of fish and wildlife. Results of the NSMA traditional knowledge study will be integrated with western science knowledge to produce a knowledge assemblage on climate and environmental change that includes human contextual experience. This approach is expected to provide insight into past climate dynamics not discernible using paleoecological approaches alone.

Suggested citation:

North Slave Métis Alliance community members, Shiga, S., Evans, P., King, D., and Keats, B. 2017. Continual change and gradual warming: A summary of the North Slave Métis Alliance's recorded cultural knowledge on climate and environmental change. Report prepared for Geological Survey of Canada Geoscience Tools for Environmental Assessment of Metal Mining (compiled by Jennifer M. Galloway3 & R. Timothy Patterson4, Project Number #1519-149); Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 99–116. DOI: 10.35298/pkc.2018.13*

Introduction

There is broad agreement among Indigenous and science communities that the climate is changing, and the rate of this change and its effects and impacts appear to be accelerated in the Arctic. Many communities in the Canadian Arctic are experiencing environmental changes that differ from normal variability. Observed differences in the seasonal extent and distribution of sea ice, fish and wildlife abundance and health, permafrost thaw, and soil erosion are considered to be without precedent (Riedlinger and Berkes 2001). In equally unprecedented ways, climate change research has brought together conventional science and Indigenous knowledge. Indigenous communities, through their long occupancy and management of their territories and through their relationship with animals and other resources, are storehouses of invaluable insights into environmental trends over *la longue durée*, the long term.

In assessing the evidence of climate change in the Arctic, Hinzman et al. (2005) find that, although a wide variety of regional changes have occurred over the course of the last 400 years, many of these changes began or accelerated in the mid-1970s. Some of the changes, such as later freeze-up and earlier break-up of Arctic rivers and lakes, mirror Arctic-wide and even worldwide increases in air temperature. Others document more subtle or complex responses of the Arctic system as it adjusts to current and longer-term trends in climate. Since the Arctic system is particularly sensitive to changes in rain and snowfall, the timing of freeze-up and break-up, and the intensity of storm activity, it is likely that much of what has been documented to date (and will be documented in the future) reflects these changes. Regardless of the driving forces, the combined observations and documentation offer substantial evidence, although often diffuse, that the Arctic system may be entering a state not seen in recent history (Hinzman et al. 2005).

This report details Métis cultural knowledge linked to climate and climate change within the North Slave Métis Alliance (NSMA) members' traditional territory north of Great Slave Lake, Northwest Territories, including cultural knowledge of climatic and corresponding environmental conditions and environmental variability, and cultural knowledge of climate change and corresponding environmental impacts. Data were extracted by the project team from interviews previously conducted with NSMA members and from a selection of primary and secondary literature that overlaps with the Métis historical experience. This notion of the Métis historical experience and what it means in terms of climate research and archival work requires some explication. Typically, climate change research with Indigenous communities focuses exclusively on traditional knowledge, with researchers (usually non-Aboriginal) looking to Indigenous oral traditions and personal observations to supply qualitative information on climate trends. This methodology reinforces the idea that Euro-Canadians have science and Indigenous Canadians have traditional knowledge. But the Métis historical experience, occurring as it does at the crossroads of Indigenous and Euro-Canadian encounters, involves unique Indigenous-European modes of subsistence, labour, and knowledge production. Métis individuals were involved in the fur economy, exploration, and science as well as traditional land use, including subsistence. As a result, the Métis traditional knowledge of climate change complements climate observations of fur traders, post workers, and explorers.

Methodology and sources

The NSMA holds a variety of records pertaining to the history of Métis in the Northwest Territories and the role of Métis in the development and operation of the fur trade on Great Slave Lake. Among these are digital copies of Warburton Pike's account of his travels to the Barren Grounds with his Métis guide King Beaulieu. It was published in 1892 as *The Barren Ground of Northern Canada*. Pike provided a day-by-day account of his journey with Métis guide Beaulieu to the east end of Great Slave Lake and then north to the Barren Grounds. In describing the party's route and decisions made along the way about when, where, and how to travel, shelter, harvest food, and gather supplies, Pike frequently revealed cultural knowledge held by his Métis companions. The project team reviewed Pike's work to extract relevant examples of Métis cultural knowledge embedded in the text.

The NSMA also holds digital copies of Hudson's Bay Company (HBC) journals that were kept by employees at Old Fort Rae on Great Slave Lake (Hudson's Bay Company Archives). Old Fort Rae is described by NSMA members as a culturally, spiritually, and historically important place for their families and ancestors. The earliest remaining HBC journals for Old Fort Rae begin in 1888. Hayden (2010) cautions that the journals for Old Fort Rae "*must be read with an understanding that the emphasis and sequence of events are representations of experiences and not a description of the experience themselves.*" However, a preliminary review of the available journals suggests her contention that "*Métis cultural perspectives are mostly missing from these documents*" may be less accurate. These records represent the experience of daily life and living conditions at an isolated outpost populated by both European and Métis individuals, and therefore, some of the journals could have been written by Métis, reflecting Métis attitudes and culture. The journals span the years 1888 to 1912, including the movement of the post and the Métis community surrounding it north from Old Fort Rae to Fort Rae (present-day Behchokǫ̀). They provide occasional data describing weather and climatic conditions at Old Fort Rae. The climate data were extracted by the project team and plotted on spreadsheets for analysis according to date, temperature, and qualitative descriptions of climatic conditions, such as impressions of wind force and direction, precipitation, and cloud cover. These qualitative weather descriptions, including "*cold,*" "*warm,*" "*cloudy,*" "*rainy,*" and "*snowing,*" were assigned numerical keys (i.e., cold = 1, warm = 2, mild = 3). The spreadsheets were then graphed and analyzed for patterns and insights into climate and environmental change during the years represented. For this report, the project team also reviewed NSMA's previous interviews for references to climate and environmental change. Although climate and the environment were not the focus of those interviews, analysis of the transcripts revealed participants sharing extensive cultural knowledge related to climate and the environment. In many cases, this knowledge was conveyed in passing as participants responded to questions about harvesting activities, travel, and other land use activities pursued throughout their lifetimes. In these instances, and where no further questions were posed during the interview to elucidate the knowledge shared, the project team's analysis included a limited amount of interpretation in order to draw out the knowledge being revealed. Further research focused on gathering Métis cultural knowledge related to climatic and environmental change, and new interviews with NSMA's entire membership are recommended. The project team also conducted a literature review of sources describing observations of climate change on Indigenous populations in the Canadian Arctic, and the Northwest Territories in particular. These included Hinzman et al. (2005), Riedlinger and Berkes (2001), Downing and Cuerrier (2011), Guyot et al. (2006), NWT Environment and Natural Resources (2008), Tam et al. (2013), James and Tristan (2010), and Duerden (2004). Further research is recommended to collect and analyze existing Métis observations of climate change.

Historical overview

The weight of evidence suggests an eighteenth-century origin for the Métis community in the Great Slave Lake area. Jones notes that "*it seems reasonable to state that [Métis] were already living in the Great Slave Lake area at the very beginning of the period of European trader residency there*" (Jones 2005:12). Records indicate that by 1800, the Great Slave Lake area was home to a burgeoning population of first-generation children of mixed ancestry, born of unions between French men and local Aboriginal women (Jones 2005:19). Métis history is firmly linked to the fur trade, and the first fur-trading post in the region was established on the southern shore of Great Slave Lake in 1786. From this post, the initial trading journey on Great Slave Lake went up through the North Arm and into Dogrib country around Lac la Martre, where another post was established in 1789. In 1790, a post was also built on the North Arm near the Yellowknife River — Old Fort Providence served as the centre of North West Company activities for the next few years (Bellman and Hanks 1998). Recent research and archaeological evidence now suggest that a post at Old Fort Rae, on the eastern shore of the North Arm, may also have been established at the same time as or even earlier than Old Fort Providence (Stevenson 2001:12,15). A map produced by Aaron Arrowsmith in 1795, and amended in 1802, makes reference to the presence of 'Canadian Settlements' on the North Arm, [and] in a footnote to Philip Turnor's 1791–92 journals, J.B. Tyrell notes that in 1789, or "*a little earlier … Laurent Leroux … built a house on the north arm of Great Slave lake, about where Fort Rae is now situated.*" An even earlier reference to a possible Métis presence in the North Arm comes from Alexander Mackenzie when he noted in 1789 the remains of an old fort on Old Fort Island (Stevenson 2000). Hanks notes that François Beaulieu II, the Métis son of François Beaulieu and his wife, Ethiba, was born during the time that European fur traders first arrived in the Great Slave Lake area. As a youth, François Beaulieu II would have seen the European traders shift from the traditional route (from Great Slave to Great Bear Lake via the Marian and Camsell Rivers) to the more westerly Mackenzie River route north. As a free trader, Beaulieu would exploit European neglect of the traditional route throughout his life (Hanks 2000). According to Hanks, local knowledge and use of the North Arm proved beneficial to the Métis as the fur trade around Great Slave Lake developed. The Métis were "*prized as fur trade employees for their language ability, skills in living on the land, and influence in the Indian population*" (Jones 2005:128). By early in the 1800s, "*an identifiable cadre of mixed-ancestry individuals affiliated with the North West Company, familiar with the country and well-connected with the local Indian population, had emerged in the Great Slave Lake region*" (Jones 2005:33).

Old Fort Rae

Old Fort Rae (referred to as Fort Rae after the post and Métis community moved north) is named after Dr. John Rae, an Arctic explorer associated with the HBC, although the site first appears in historical records as Mountain Island or Rae Point (Hayden 2010:2). Local knowledge and other evidence presented in Stevenson indicate a possible Métis presence at Old Fort Rae as early as 70 years before the arrival of the HBC: "*Chief among [this evidence is] the late Edward Lafferty's statements that Old Fort Rae's cemetery contains numerous graves which predate the arrival of the Catholic Church (i.e., 1859) by many decades, and that these burials were so old that no one, not even his grandparents, could remember who they belonged to.*" (Stevenson 2000:6). Stevenson also cites several historical records indicating the North West Company (NWC) established a trading post at Old Fort Rae in 1804, and "*Métis freemen may have settled on the shores of Great Slave Lake and its North Arm years in advance of the NWC*" (Stevenson 2000:8). In fact, Stevenson finds it most likely that archaeological evidence found at Old Fort Rae points to "*a pre-1780 occupation of Métis freemen formerly associated with the Company of the Sioux, or a late-1780s/early 1790s occupation of Métis dating to the heyday of NWC trading activity on the North Arm*" (Stevenson 2000:10). Hayden agrees that the archaeological evidence offers proof of a Métis settlement at Old Fort Rae several decades prior to the arrival of the HBC. She concludes that Métis use and occupation of the site likely began with the NWC in 1804 (Hayden 2008:8). The NWC moved into the North ahead of the HBC and first established a trading post at OFR [Old Fort Rae] in 1804 called Mountain Island Post, which was abandoned by 1820. In 1849, Dr. John Rae was granted permission by George Simpson to establish a post at Marten Lake, its main purpose to procure provisions for the other posts rather than to collect furs. In 1851, Chief Trader James Anderson, John Rae's successor at Marten Lake, requested that the HBC move a post to the mouth of the Marten River at a place called Montagne de l'Isle, which would allow for trade to occur with both the Marten Lake (Tłı̨chǫ) and the Copper Indians (Yellowknives Dene). The suggestion stemmed from advice given by freeman and independent trader Baptiste Beaulieu. By June 1852, Anderson gave Charles Gaudet instructions to build a fort at the straits of Lac Brochet, a place called Fort Rae, and appointed Alexander McKenzie to its charge. That summer, Mr. Gaudet, Cadien, the interpreter, and five Indians built the fort near the old "Post of Montagne de l'Isle" and called it Fort Rae (Hayden 2010:4). According to Bellman and Hanks (1998:53), Anderson also sought advice from François Beaulieu on where best to locate the new HBC fort, but opted to follow Baptiste Beaulieu's recommendation for the east side of the North Arm instead. In addition to wood supplies and a reputation as a good fishing area, this location boasted two particular assets: direct access to caribou during their spring and fall migrations (Stevenson 2001:16) and proximity to important spiritual/cultural sites, which made it easier for "*local hunters and trappers to remain within culturally significant territory while participating in the new economic trade system*" (Hayden 2010:26–27). Stevenson notes that the fort was 150 miles "*off the 'beaten track' of the main fur trade route*" (Stevenson 2001:16), and therefore received very few travellers. He asserts that this geographical isolation led to the development of a distinct Métis identity, marked by its hybridization of French-Canadian and local Dene cultural and economic practices. Stevenson describes how a shared sense of community and cultural identity likely crystallized among the Métis inhabitants at the fort:

> *At Old Fort Rae the Métis language was dominant, Métis clothing was worn, and the Catholic religion and burial traditions of the Métis were practised. The social organization of work was distinctly Métis, with its division and specialization of labour. The permanent homes around the fort reflected a unique Métis architecture: they were permanent structures with root cellars and intricate dove-tailed corners which differed from the semi-permanent Dene homes. (Stevenson 2001:17)*

The list of early HBC employees at the fort begins with Louison Cadien, the interpreter mentioned above, who "*appears to have lived at Old Fort Rae throughout most of the 1850s and was responsible for re-opening the fort in 1852, when he built five log huts there*" (Stevenson 2001:16). Cadien, or Cayen, also known as Old Cayen, was most likely the Métis son of a Parisian who had worked for the HBC and lived among the Chipewyan several decades earlier (Bellman and Hanks 1998:41). Jones observes that during the mid-nineteenth century, while some Métis moved in and out of HBC employment, and in and out of residence at HBC forts, "*long-time mixed-ancestry employees like Pierre Blondin and Louis Cadien continued to make their living as workmen, boatmen, interpreters and emissaries to the Indians, and new mixed-ancestry families were formed from year to year around the HBC posts*" (Jones 2005:71). Assessing marriage and baptism records made by Roman Catholic church officials at Forts Resolution and Providence during the mid-1800s, Jones observes that "*the links between old and new mixed-ancestry and (primarily) French-ancestry families are evident, as well as some continuing, but limited outmarriage to Dene women*" (Jones 2005:78).

Louison Cadien, Oliver and Louison Laferté, and Alexis and King Beaulieu, are all listed as HBC employees in the Old Fort Rae account books for 1853 to 1863, along with Pascal and William Houle, Baptiste Bouchez dit Lamalice, and Baptiste Mainville (Jones 2005). Several names "*associated with French-Canadian or mixed-ancestry employees of the Company in earlier years*" are listed among Old Fort Rae's "Indian" accounts for this same period, including Beaulieu, Robillard, and Marseillais (Jones 2005:79). The account books for the 1870s and 1880s include Baptiste Bouvier as an employee, along with names such as Laferté, Beaulieu, Hoole, Camsell, Norn, Villeneuve, and Laviolette (Jones 2014:14). Henry Cadien is listed at different times as an employee, middleman, and interpreter, and as an "*Indian*" or having "*Indian debt*," along with "'*Small Man Beaulieu' and his son … 'Old Man Beaulieu' and 'Beaulieu's 1st son'*" (Jones 2014:15). Jones surmises that "*Indian debt*" was perhaps "*more a type of economic relationship than an ethnic attribute*" (Jones 2014:18). Hayden also provides a snapshot of people at Old Fort Rae:

> *The mostly Métis men and boys working as post servants spent the majority of their days hauling wood for heat, building materials, and fuel; transporting furs; fetching, drying and preparing meat; constructing and maintaining post buildings, sleds, coffins and other necessary equipment; repairing nets; fishing; and hunting. The women of the posts are rarely mentioned in the journals aside from their journeys to the Syrup Camp in May and some berry-picking and trapping trips, but they presumably played a major role in raising the children and carrying out other household and community duties. (Hayden 2010:34)*

The workers performed the same types of construction and manual labour tasks as their counterparts did at Fort Providence. In the winter, the employees and Antoine Laferté made several trips with dogsleds to locations within a few days' travel of the post to collect furs and meat from the HBC's trading partners. They also travelled about the same distance to cut wood to heat the post buildings and to supply the steamer Wrigley on its summer visits. Fishing was done every day for about six months of the year in open water or under the ice near the fort. David Villeneuve, Henry Cadien, and other employees operated fisheries for the post, especially in the fall, at Jackfish River, Smith's Island, the "*Island Fishery*," "*the point*," and other unnamed locations. The HBC's customers, such as Beaulieu and his sons, Tom Cook's son, and Rabasca, visited the fort once or twice a year to trade meat or furs (Jones 2014:15–16).

Arthur Camsell's post journal from Old Fort Rae offers a glimpse of life at the fort during the late 1800s, including the marriage of Antoine Laferté to Madeleine Beaulieu in October 1890 and the birth of Alexis Beaulieu's son in November of the same year. He notes a number of celebratory dances lasting until the early hours of the morning and records a variety of Métis harvesting activities, including hunting and making birch syrup (Jones 2014:16). A declaration of Marie Laferté (wife of Alexis Beaulieau), dated February 28, 1894, concerning her "*claim to participate in any grant to Half-Breeds living in the North West Territories*" records the dates of the births and deaths of her children: "*Isabelle born in Fort Resolution in 1879, died in Fort Rae aged 1 year, one died at birth nine years ago … he was born and died at Fort Rae + Maria Rosa born at Fort Rae 7 years ago died … 1893*." Jones's review of the post journals "*for the years 1892-1899 and 1900-1904 shows similar patterns of trading, local resource harvesting, and labour*," and the accounts for the same period show a similar assortment of Métis names (Jones 2014:18).

In 1893, the HBC trading post faced new competition from a neighbouring outpost that was established by Hislop and Nagle less than 20 miles to the north. Acting on the advice of Alexis Lafferty from Old Fort Rae, "*Hislop set up a post near the Willow River - a location the Dogrib had previously recommended to the Hudson's Bay Company, since it was at the centre of Dogrib territory*" (Bellman and Hanks 1998:66). The 1901 census combined residents of the two posts together, enumerating six mixed-ancestry families at Old Fort Rae and at nearby Willow River. Family members were recorded as having been born at Fort Rae and at other outposts on Great Slave Lake (Jones 2005:105). By about this time, however, the movement of Métis families away from Old Fort Rae to Willow River and eventually to the new HBC post in Rae had begun. Stevenson (2001:21) has the move beginning in 1901 and concluding in 1906, with HBC continuing to operate at Old Fort Rae until 1911. Hayden places the move in 1905, with HBC journal entries at that time detailing the ongoing construction of the new fort at Rae as well as providing "*evidence of the Old Fort still being inhabited by the 'Old Fort Indians'*" (Hayden 2010:39). According to Stevenson, by 1916 the considerable number of Lafferty family members, "*headed by Henri Lafferty,*" were the sole residents of Old Fort Rae (Stevenson 2001:21).

Hayden writes of Alice Lafferty and her family:

> *Although Alice [Lafferty] was not alive to witness the trading practices of the HBC at [Old Fort Rae], her family and life history highlight the continued use of that area by the Métis families that once served there … Even though the hub of economic activity had shifted slightly, to Fort Rae and Yellowknife, many families remained on the land to pursue more traditional lifestyles. (Hayden 2010:39)*

Historical climate data from traditional Métis territory

Hudson's Bay Company journals

The purpose of the journals maintained at every HBC post was to record an objective account of operations for managerial and reporting reasons; however, "*often in the course of doing this, journals would also present information considered vital to understanding the larger world in which the HBC placed itself and its business enterprise*" (Province of Manitoba 2015). Included in this type of information were measurable observations of climate and related environmental conditions, such as temperatures, and qualitative observations, such as wind and seasonal changes. Posts were not required to record meteorological information; rather, it was noted according to the whims and interests of the journal keepers. As a result, the regularity and frequency with which the journals provided weather data differ greatly from post to post, author to author, and even day to day. For this report, the project team reviewed all of the HBC journals currently held by NSMA, namely those from Old Fort Rae, because of the post's importance to NSMA members and its central role in the lives of their families and ancestors. With respect to future research, it is recommended that the HBC journals for the posts at Fort Simpson, Fort Providence, and Fort Resolution, at a minimum, be reviewed, and data analyzed and amalgamated with the data provided here for Old Fort Rae, as well as a review of account books, which may contain information on fur conditions that could be correlated with climate data and traditional knowledge. Of Old Fort Rae's data sets, temperature is the most consistently available because it was sometimes recorded on an almost daily basis, and therefore proved the most useful for analysis. However, even temperatures were recorded inconsistently over the course of each year, with many days, weeks, and months entirely unaccounted for, so the project team focused its analysis on two select periods during which temperatures were well represented over multiple years. The two periods selected for analysis were November-December and January-February, because unlike most other periods covered by the journals, temperatures during these months were recorded on an almost daily basis over multiple years between 1888 and 1896. Available temperatures for these months/years were first plotted in tables for comparative analysis, and then used to generate graphs to illustrate the variability and fluctuation of daily temperatures during the same periods from year to year (Fig. 1, 2). The graphs for both periods appear to describe continual change in temperatures during each period and between the same periods each year. The available data suggest what might be described as "consistent inconsistency" in temperatures and corresponding climatic conditions for the periods analyzed. Temperatures appear to fluctuate within a range of 6°F to 8°F within each period, and without adhering to any predictable pattern.

John Franklin's expeditions

During the 1820s, the British explorer John Franklin made two expeditions to the north coast of Canada, aided on both journeys by the local knowledge and physical labour of Métis individuals, referred to throughout the accounts as "*half-breeds*," "*voyagers*," and "*Canadians*." During each of these voyages, "*regular measurements were made several times each day of temperature, wind direction, and compass variation, as well as observations of wind speed, precipitation, sky cover, and the occurrence of the aurora*" (Hopper 1985:684). Much of this early climate data is preserved in the expedition journals that were kept by Franklin for the purpose of publication and in the personal journals kept by the naturalist John Richardson, who accompanied Franklin on his first expedition (Hudson's Bay Company Archives). Existing analyses of these data underscore the day-to-day and year-to-year variability of temperatures recorded at outposts close to Old Fort Rae and located within NSMA members' traditional territory in the region north of Great Slave Lake. For example, Hopper gives the following analysis for December 1820 and January 1821:

> *The meteorological observations at Fort Enterprise suggest a typical winter in many respects … except for an unusually cold December the expedition experienced mean temperatures which were normal or higher than normal. January 1821 was by contrast unusual … There was a short cold spell followed by return of the mild weather in the middle of the month. No rain fell at Fort Enterprise, but the expedition experienced several days of 'a kind of damp fog approaching very nearly to rain.' (Hopper 1985:686)*

By contrast, Houston observes that later in 1821 at Fort Enterprise, Franklin and his officers documented an early winter:

> *In October 1820 at Fort Enterprise "there had been very little snow on the ground, and we were surrounded by vast herds of reindeer… Winter River was then open." In October 1821 "there were but few recent tracks of these animals, and the snow was upwards of two feet deep… Winter River… was frozen two feet thick." G. C. Jacoby's unpublished tree-ring studies from the Coppermine Mountains confirm that Franklin encountered a major dip in temperatures in 1821. (Houston 2014:208)*

In their analysis of historical Arctic climate data, including Franklin's, Przybylak and Vizi suggest the 1820s were warmer overall, particularly during the winter months, than the 1850s, when Old Fort Rae was established (Przybylak and Vizi 2005:1512). They also note, however, that even these warmer winters were considerably colder than those the region experiences today. Additionally, they report that variances between mean daily temperatures were greatest during winter and summer months, and that these variances have increased in both frequency and severity from the past to the present. The greatest changes in the day-to-day variability of mean daily air temperature (MDAT) from historical to present times occur in winter and especially in summer. In both seasons, increases in variances were noted. This means that at present, the occurrence of large day-to-day MDAT variability (exceeding 5°C in winter and 3°C in summer) is more frequent, while small variability (0°C to 1°C) is less frequent (Przybylak and Vizi 2005:1515).

The tables from Franklin's *Narrative of a Second Expedition to the Shores of the Polar Sea in the Years 1825, 1826, and 1827* illustrate the daily changeableness of temperatures recorded at Fort Franklin on the southwestern tip of Great Bear Lake during the same months selected for analysis from the HBC data for Old Fort Rae, namely November-December and January-February for the years 1825 to 1827 (Franklin 1828).

The Meteorological Council of Great Britain

In 1879, the British Meteorological Council published Contributions to our Knowledge of the Meteorology of the Arctic Regions, which "*collected together the information as to the climate of the Polar Regions, especially of the portion in the vicinity of the American Continent, contained in the log books and journals of the various British Arctic Expeditions up to the year 1874.*" This included the temperature data recorded by John Rae at Fort Confidence in the Northwest Territories during the winter of 1850–51 and by Lieutenant W. J. S. Pullen at Fort Simpson from the fall of 1849 to the spring of 1851.

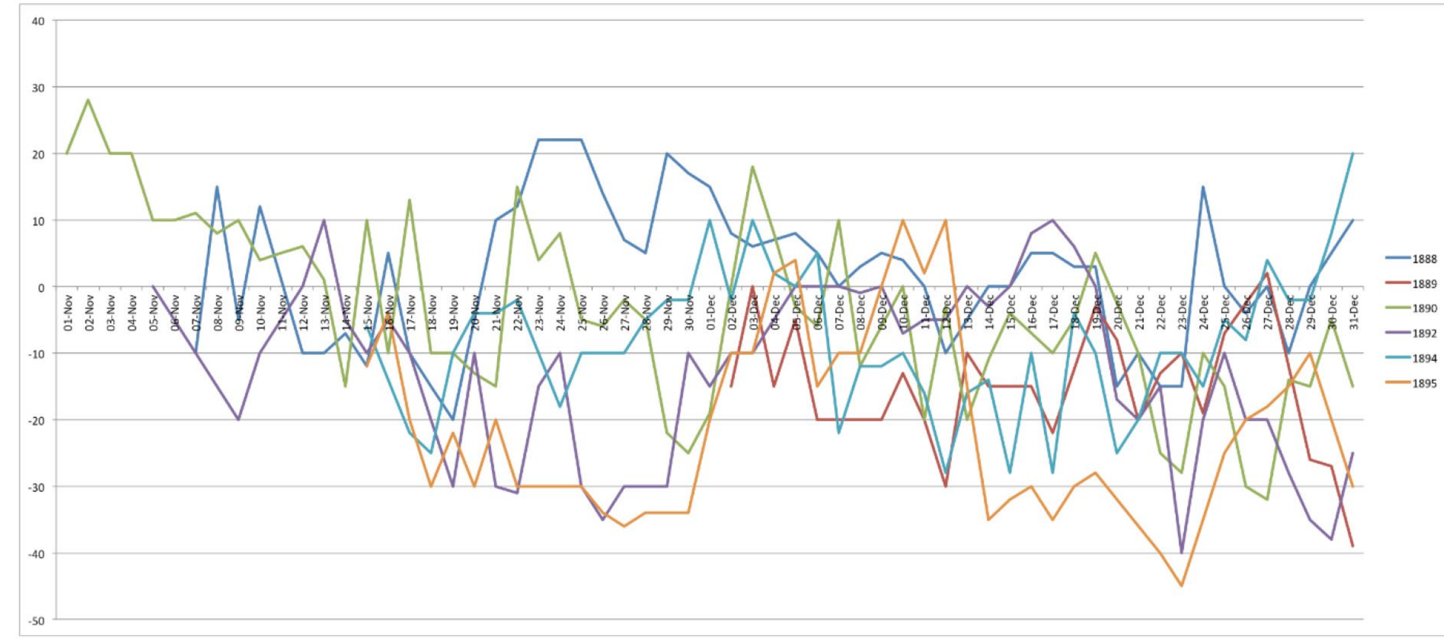


Figure 1: Available temperatures (°F) extracted from HBC journals for November-December 1888, 1889, 1890, 1892, 1894, and 1895 (Hudson's Bay Company Archives).

Fort Simpson

During the summers of 1849 and 1850, W. J. S. Pullen led expeditions by boat to search for the Franklin expedition that had gone missing four years previous. During the remaining months of both years and until the spring of 1851, Pullen returned to pass the winters at Fort Simpson, an HBC post, near the confluence of the

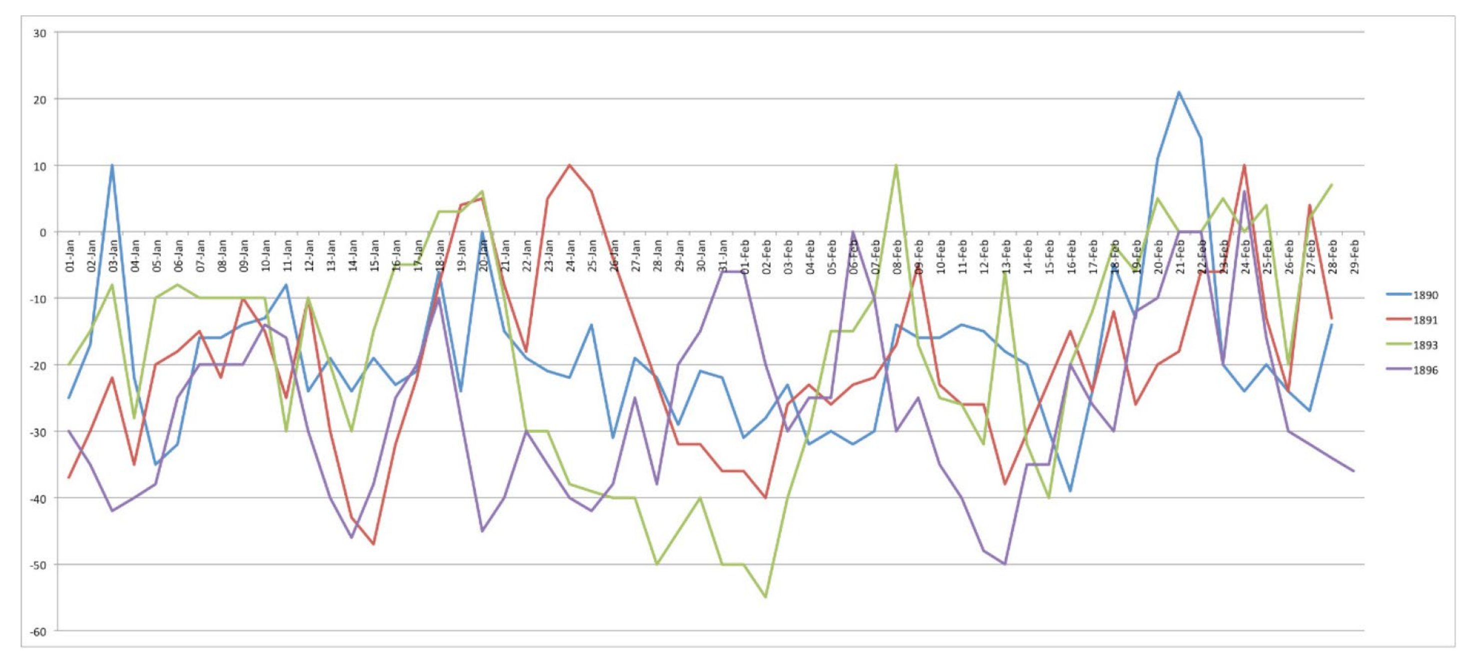


Figure 2: Available temperatures (°F) extracted from HBC journals for January-February 1890, 1891, 1893, and 1896 (Hudson's Bay Company Archives).

Mackenzie and Liard Rivers, east of Great Slave Lake. Here Pullen made regular temperature recordings with "*no less than twenty-two thermometers in the open air*" (Meteorological Council 1879:345). Tables from *Contributions to our Knowledge of the Meteorology of the Arctic Regions* show the monthly temperatures recorded by Pullen during the same months selected for analysis from the HBC data for Old Fort Rae, namely November-December and January-February, for the years 1849–50 and 1850–51. In November-December of 1849, temperatures ranged from 9.1ºF to –15.7ºF and in the same months in 1850, temperatures ranged from 15.4ºF to –9.4ºF. In January-February of 1850 and 1851, temperatures ranged from –30.5ºF to 1.4ºF and –23.1ºF to –4.5ºF respectively (Meteorological Council 1879).

Fort Confidence

Fort Confidence was established on the northeastern shore of Great Bear Lake in the mid-1830s. Although financed by the HBC, the Fort was not a trading post but a base station for Arctic expeditions, such as the one John Richardson and John Rae led in 1849, also in search of the missing Franklin expedition. When the two returned to Fort Confidence in 1850, John Rae remained at the fort throughout the winter, where he recorded meteorological data, including temperatures, from October 2, 1850, to June 6, 1851 (Johnson 1975:239; Meteorological Council 1879;11). In publishing Rae's data, the Meteorological Council notes that the climate in the territory surrounding Fort Confidence is "*subject to sudden and great changes of temperature*" (Meteorological Council 1879:11). In contrast to the temperatures recorded by Franklin and his officers during the 1820s, which showed the greatest change in daily temperatures occurred during the winter and summer, Rae's records show that for the winter of 1850–51, "*the mean daily range of temperatures was very small in November, December and January, and very large in February, March and April*" (Meteorological Council 1879:11).

International Polar Year

1882–83 marked the first International Polar Year (IPY), during which "*scientists from 11 countries ran 12 expeditionary stations in the Arctic or sub-Arctic and two in the sub-Antarctic for about 13 months*" in order to collect meteorological data systematically for the purposes of scientific analysis and publication (Bulkeley 2010:1). Despite some initial reluctance on the part of the British Royal Navy to participate, due in part to the opinion that it was impractical and counterproductive to have researchers stationed in one place for a year rather than exploring an area for the same duration, the Meteorological Council eventually won out and selected Old Fort Rae as the site for its IPY base (Barr 2010:61). The fort was "*not only the northernmost of the HBC stations, it was also nearest to the Magnetic Pole and thus advantageous for the IPY programme*" (Barr 2010:61). Captain Henry P. Dawson was selected to lead the expedition to Old Fort Rae. Owing in no small part to the infrastructure, fish, and game that Dawson and his men were supplied with there, it was among the least hazardous or difficult of all the IPY expeditions (Barr 2010:61,63). Perhaps indicating Métis cultural knowledge of climate, HBC personnel reported that the winter of 1882–83 "*was an unusually mild winter with a very late start, much lighter snowfall than usual and unusually few severe storms*" (Barr 2010:62). Dawson reported that there was scarcely any ice at all in the Mackenzie River at the end of November, "*whereas it is usually full of drifting ice in October, and frozen over in November*" (Wood and Overland 2006:8). According to Wood and Overland, "*the median freeze date for the Mackenzie River at Fort Simpson, based on 44 yrs. of observations between 1931 and 1985, is 25 November, but dates range from as early as 31 October to as late as 15 December*" (Wood and Overland 2006:8). Just as these reports and analyses suggest the variability of seasonal conditions from one year to the next, Dawson's further description of the 1882–1883 winter speaks to the variability of temperatures from day to day and week to week within NSMA members' traditional territory:

> *It was not until the beginning of December that our winter really set in, but when it did so there was no mistake about it, as the 1st of the month began with the thermometer at –34F, and except for some mild weather at Christmas, the cold continued through that month. January was colder still, the thermometer once or twice approaching –50F, but in the early part of February a violent storm was accompanied by a remarkable rise of temperature (to +20F), and followed by some mild weather, since which the thermometer has again fallen, reaching –39F a couple days ago. (Barr 2010:61–62)*

Daily surface air temperatures (SAT) and sea-level pressures (SLP) recorded at Old Fort Rae during the IPY document a range of SAT of approximately –5ºC to –39ºC in the months of November and December and –15ºC to –40ºC in the months of January and February. Large fluctuations in temperature in a short period are rare from April to October and no greater than approximately 15ºC from November to March. Documented SLP ranges from approximately 1000 hPa to 1040 hPa for the entire year (NOAA Arctic Research Office). As Wood and Overland point out, "*these observations span only a single year, but offer a unique glimpse of the circumpolar environment from a period before the present era of Arctic warming*" (Wood and Overland 2006:11).

Cultural knowledge on climate and environmental change

Warburton Pike

When the British gentleman-adventurer Warburton Pike set out to hunt muskox in the Barren Grounds of the Northwest Territories in 1889, he hired King Beaulieu as his guide (despite his assertion that "*nobody could give him a very good character*"), because Beaulieu was known to be a "*first-rate traveller, besides having made a successful musk-ox hunt in the previous year.*" Pike then elaborated on Beaulieu's qualifications, describing him as "*expert in all the arts of travel with canoes or dog-sleighs, [and] quick in emergencies*" (Pike 1892:18). The "*arts of travel,*" part of what we would call traditional knowledge today, would have included extensive knowledge related to climate and the environment. The modes of transportation described indicate that Beaulieu's knowledge extended to all the seasons and weather conditions northern travellers might encounter. Later in his account, Pike provided the following description of Beaulieu and the other Métis deploying their specialized knowledge to respond to seasonal weather-related changes in the terrain:

> *I now saw an example of the readiness of idea which King possessed in devising shifts and expedients to get out of difficulties … Before I thoroughly understood his scheme we commenced operations, by lashing together all the poles and paddles into a rough sort of ice-raft; on the top of this we placed the loads that we had carried so many miles, forming a smooth bed, two feet above the level of the ice, on which to rest the canoe. The bay had evidently frozen and broken up once, and the second freezing had left a rough surface; many of the floes were piled on top of each other, while the rest had been turned on edge, and it was necessary to keep the canoe clear of these sharp edges, which wsould have ripped the tender birch-bark like a knife. One man ran ahead, trying the strength of the ice with an axe, while the others hauled on the raft, and our method of progressions was so satisfactory that just before dark, after much ominous cracking of the ice but no disaster, we camped on the east point of the bay close to the edge of open water. The half-breeds showed great knowledge of ice, and, with an occasional tap of the axe, picked out the safest route without making a mistake. The canoe propped on her side gave us the best shelter we had had for many a night, and, finding willows enough for a fire, we all felt jubilant at the idea of reaching the first clump of pines on the following day. (Pike 1892:68–69)*

Upon reaching the Barren Grounds, Pike's Métis companions demonstrated cultural knowledge of winter camp construction, including the dual purpose given to snowshoes and sleds, which the Métis employed as tools and structural enhancements:

> *A spot being chosen where the snow is light and the ground clear of rocks, a ring of the requisite size is marked out. Snowshoes are taken off and used as shovels for throwing away the snow from the inside of this ring, making a wall varying in height according to the depth of snowfall. Outside this circle the sleighs are turned on edge, the poles planted behind them, and the deerskin lodge spread round, forming as comfortable a camp as can be expected in such a country. (Pike 1892:94)*

Jones provides a summary of some of the early action described in Pike, which offers insight into the nature and range of the cultural knowledge Beaulieu held:

> *King Beaulieu took the party on a chain of lakes route Pike speculated had not been travelled by white men before, east of the Yellowknife River and west of the route taken by Back to the headwaters of the river that now bears his name. They camped on a lake called by the Beaulieus "du Rocher" (now known as Warburton Bay), which "the half-breeds … have always found a certainty for caribou at this time of year." About a day's travel away, Beaulieu's sons found a herd of caribou. (Jones 2014:39–40)*

Pike himself characterized the route Beaulieu selected as a part of Beaulieu's cultural knowledge, indicating the existence of places previously named by the Métis along the way, and more importantly, Pike illustrated Beaulieu's knowledge of caribou behaviour related to climate and seasonal environmental conditions. Pike wrote:

> *We continued our journey as before, pushing on as quickly as possible to reach the Lac du Rocher, where the half-breeds were confident of meeting the caribou, or, at the worst, to camp at a spot well known to them where we might catch fish enough for temporary support … On September 13th we reached the Lac du Rocher … Others explored the surrounding hills for caribou tracks, but without success. The half-breeds were all much put out by this failure, as they have always found the Lac du Rocher a certainty for caribou at this time of year, and were unable to account for it, except by the theory that the animals had altered the usual course of their autumn migration and were passing to the east of us. (Pike 1892:36–37)*

It is evident that the Métis travelling with Beaulieu knew where the caribou had traditionally been according to seasonal and climatic conditions. Their certainty about where to find them, disappointment at their failure to do so, and their theorizing that the herd had altered its course, all led to Pike's subsequent assertion that "*the caribou are extremely uncertain in their movements, seldom taking the same course in two consecutive years*" (Pike 1892:46). However, the experience at Lac du Rocher that Pike recounted, as well as the following observation, suggest at least developing Métis knowledge of changes to caribou behaviour related to environmental change.

> *I think there is really much truth in the statement that they keep a more easterly route than formerly, as they seldom come in large quantities to the Mackenzie River, where they used to be particularly numerous in winter. This is in great measure accounted for by the fact that great stretches of the country have been burnt, and so rendered incapable of growing the licken [sic] so dearly beloved by these animals. The same thing applies at Fort Resolution, where, within the last decade, the southern shore of the Great Slave Lake has been burnt and one of the best ranges totally destroyed. (Pike 1892:46)*

According to Pike, Beaulieu often shared traditional stories with him, "*usually some tradition handed down from the time when all the animals and birds could converse together*" (Pike 1892:78). Pike called one of the stories "*the Deluge*," and transcribed it from Beaulieu's telling. It is an origin story that hinges on climatic events, suggests cultural knowledge of continual change in seasonal climatic conditions, and is embedded with examples of climate-related cultural knowledge such as the ptarmigan turning white when the snow begins to fall:

> *Many years ago, so long ago in fact that as yet no man had appeared in the country of the Slave Lake, the animals, birds, and fishes lived in peace and friendship, supporting themselves by the abundant produce of the soil. But one winter the snow fell far more heavily than usual; perpetual darkness set in, and when the spring should have come the snow, instead of melting away, grew deeper and deeper. This state of affairs lasted many months, and it became hard for the animals to make a living; many died of want, and at last it was decided in grand council to send a deputation to Heaven to enquire into the cause of the strange events, and in this deputation every kind of animal, bird, and fish was represented. They seem to have had no difficulty in reaching the sky, and passing through a trap-door into a land of sunshine and plenty. Guarding the door stood a deerskin lodge resembling the lodges now in use among the Yellow Knives; it was the home of the black bear, an animal then unknown on the earth. The old bear had gone to a lake close at hand to spear caribou from a canoe, but three cubs were left in the lodge to take care of some mysterious bundles that were hung up on the cross-poles; the cubs refused to say what these bundles contained and appeared very anxious for the return of the old bear.*
>
> *Now the idea of spearing caribou did not find favour with the deputation from below, and as the canoe was seen lying on the shore of the lake, the mouse was dispatched to gnaw through the paddle, and as he had nearly accomplished this feat the bear came running down in pursuit of a band of caribou that had put off from the far shore. When he was close up to his intended victims and was working his best, the paddle suddenly broke, the canoe, capsized, and the bear disappeared beneath the water. Then the animals, birds, and fishes grew bold, and pulling down the bundles, found that they contained the sun, moon, and stars belonging to the earth; these they threw down through the trapdoor to lighten the world and melt the snow, which by this time covered the tops of the tallest pine-trees. The descent from Heaven was not made without some small accidents. The beaver split his tail and the blood splashed over the lynx, so that ever afterwards till the present day the beaver's tail is flat and the lynx is spotted; the moose flattened his nose, and many other casualties occurred which account for the peculiarities of various animals, and the little bears came tumbling down with the rest.*
>
> *And now the snow began to melt so quickly that the earth was covered with water, but the fish found for the first time that they could swim, and carried their friends that could not on their backs, while the ducks set to work to pull up the land from beneath the water. But it was still hard to make a living, so the raven, then the most beautiful of birds, was sent to see if he could find any place where dry land was showing; but coming across the carcass of a caribou he feasted upon it, although the raven had never before eaten anything but berries and the leaves of the willow. For this offence he was transformed into the hideous bird that we know, and to this day is despised of every living thing; even omnivorous, man will not eat of the raven's flesh unless under pressure of starvation. The ptarmigan was then sent out and returned bearing in his beak a branch of willow as a message of hope; in remembrance of this good action the ptarmigan turns white when the snow begins to fall in the Barren Ground, and thus warns the animals that winter is at hand. But the old life had passed away and the peace that had reigned among all living things was disturbed. The fish, as the water subsided, found that they could no longer live on the land, and the birds took to flying long distances. Every animal chose the country that suited it best, and gradually the art of conversation was lost. About this time too, in a vague and indefinite manner about which tradition says little, the first human being appeared on the shore of the Great Slave Lake. (Pike 1892:78–81)*

Pike indicated that "*King and his son François were the best linguists of the party*," and were in fact, two of only "*three or four*" Métis he could understand at all (Jones 2014:40; Pike 1892:26). Pike occasionally credited King with having provided place names, stories, or other information, as when he referred to sleeping without shelter and "*finding ourselves covered with an extra blanket of snow (le couvert du bon Dieu, as King called it) in the morning*" (Pike 1892:58). But his account is frequently coloured with specific and elaborate information for which he did not provide a source. It is possible then, and perhaps likely, that highly specific local climate and environment-related knowledge displayed in passages such as the one below was provided to Pike by Beaulieu:

> *In the afternoon we put out in a calm to paddle across the open traverse to the first of a group of islands about fifteen miles to the north. This traverse is the terror of the lake for canoes, both in summer on account of the heavy sea which gets up suddenly, and in winter when the drifting snow in stormy weather obscures everything and makes it a difficult matter to keep the course over the ice. (Pike 1892:25–26)*

A similar passage offered an unattributed explanation for the name of a place that was a Métis camping and fishing site strategically located where they had been windbound, as Pike (1892) writes, "*we were wind-bound again, and indeed for several days made very little headway against the northerly gales that seem almost incessant at this time of year*" (28).

> *A hard day's paddling brought us to a spot known as the Inconnu Fishery, situated on an island halfway to Fond du Lac. The Inconnu, or Unknown Fish, is … named by the early voyageurs of the Company, who were unable to classify it, and even to this day there is a great variety of opinion as to what family it is a member of … At this particular island it will take a bait readily, but I never heard of its doing so in any other part of the lake, although large numbers are caught in nets. There is some peculiarity in the water which may account for this, as, even in the dead of winter, there is generally an open hole in the ice; and, in passing the Inconnu Fishery, one must keep right ashore to avoid the treacherous spot. (Pike 1892:27–28)*

Pike's account is peppered with this contextual climate- and environment-related knowledge, presumably gleaned from but only occasionally attributed to his Métis guides, which provides a late-nineteenth-century snapshot of existing and evolving Métis cultural knowledge.

North Slave Métis Alliance transcripts

As mentioned earlier, an analysis of the transcripts of interviews conducted for NSMA's previous traditional land use studies revealed NSMA members sharing extensive cultural knowledge related to climate and the environment. In many cases, this knowledge was conveyed in passing as participants responded to questions about harvesting activities, travel, and other land use activities pursued throughout their lifetimes. In these instances, and where no further questions were posed during the interview to elucidate the knowledge shared, the project team's analysis included a limited amount of interpretation in order to draw out the knowledge being revealed. The transcripts demonstrate NSMA members' extensive knowledge of the winds and corresponding wave action on Great Slave Lake, and the North Arm specifically. Participants reported planning travel routes according to their knowledge of winds and wave action in the North Arm, as well as selecting destinations, timing, and even modes of transportation based on this knowledge:

> *In this area here, the North Arm, the lake water can go up and down four feet depending on wind direction, and that's just daily occurrence and that. There's people that've gone in, take a motorboat in some of those bays, and wind change direction, starts blowing out of the north, and then their boat is stranded out on the mud flats. So you've got to be careful where you park… When you get past Old Fort there, that whole North Arm there north of Old Fort Island is only about 12 feet deep. There's not any really deep places in it. And if you get a good north wind coming out of there to push all that water past Old Fort Point, and it'll just suck it out into all of these bays up in here. Which is part of what makes it such a good area in there, it's flushing in and out all the time… In the fall there is really good, I don't know, quality fish. I've only taken a few out of there, but you get a pretty good volume of whitefish running up through there, like to the falls and rapids. (TUS#694, 2015)*

For these weather-related reasons, Old Fort Island on the west side of the North Arm is a traditional landmark and destination for Métis travellers and harvesters:

> *[At] Old Fort Island we looked around a bit. There was some signs of people having camped there. Some people go down moose hunting there in the fall. It's a pretty good area actually along that side. But you know in the fall you can get some wind too, so you have to have a good boat to get there and back. (TUS#694, 2015)*

Other participants indicated knowledge of the challenging wind and water conditions in the area when they reported avoiding the North Arm altogether, specifically because of these factors:

> *I don't like traveling on the North Arm 'cause it's dangerous water in there. It's really unpredictable, and it actually has a tide too. You know where Bear Healing rock is? Well, right at the end, it's on this side of Behchoko, or Frank's Channel, couple kilometres on the lake side, the water goes down about this much when it's at the bottom end. I couldn't believe it either. So, it affects the whole North Arm, and so at the top of your waves, and they can get pretty big out there, you got ground on the bottom, and boats don't float on ground. So there's been a lot of accidents out there, and they still haven't found a lot of people because of that. Plus there's a lot more reefs in there, it's not as deep as the other side. So, and there's no trout in that area. There's whitefish and jackfish and conies and things like that, but there's no trout in that area. (TUS#817, 2015)*

Interview participants described a practice of making offerings of matches or tobacco to the waves near Old Fort Rae. Indeed, displaying knowledge of environmental change, they indicated that because water levels in the North Arm had gone down and wave action had diminished, such offerings then made passage possible beyond points that historically required portaging near Old Fort Rae. NSMA's interview transcripts suggest the practice of leaving offerings to protect from storms and bad weather and to ensure favourable conditions for safe travel, particularly by boat, is common throughout its membership:

> *[Métis] always leave something behind, you know, as an offering. Yeah, even when you fish, like, or when you are going out in a boat. Like, you can offer tobacco to the water for a giving, to give you a safe trip, you know. And ask for, to the spirits, to guide you there safely and bring you home safely [because] you're going out to put food on your table and feed your family and that kind of thing. Yeah, usually, like, you would offer, when you do catch something, you offer some of that food to the fire because the fire is the one that is sort of feeding you, that is going to feed you. So, whenever I go out on a boat I always give tobacco to the water, and when I'm out and if we get ducks or something like that I'll give some to the fire… That's like your role in the whole grand scheme of things, like… trying to be respectful to the land. (TUS#5, 2001)*

With respect to climate change, interview respondents reported knowledge of a general warming of both weather and water temperatures, which had driven fish deeper in search of colder water. Respondents indicated that they had adapted to this change by fishing in deeper water for the same fish they had caught previously in shallower water at the same time of year. They also reported decreasing water levels on Great Slave Lake beginning in the 1970s, with water levels at the time of the interviews measuring three to four feet lower than in the past. Interviewees reported that weather patterns had changed considerably, bringing warmer, shorter winters that were marked by less snow and more wind. Historically, seasonal weather conditions had driven the development and selection of different Métis fishing techniques, some of which, participants explained, were no longer practised due to environmental impacts associated with climate change. The following exchange between the interviewer and one participant described a traditional Métis fishing technique that was developed when "the ice used to be thick":

> Participant: *In the wintertime, about after Christmas, the ice is thick, cold. Used to be four or five feet deep, eh. So they used to put a hook there and another one, the length of the net, eh. Put another one there, so trout gets caught there and gets caught over there. Then together they would swim around, they get caught, together. So, when you come to pull on it, you know they are together, so you put another line on it, and then pull it out there and you got a line under the ice, eh. Now all you got to do is put your net on there, and set your net. (laughs) They used to set a net that way. That's how they used to do it. Smart, eh?*
>
> Interviewer: *The Métis would do this?*
>
> Participant: *Yeah, they used to do that, yeah. Sure, the ice was thick so all you had to do was punch two holes. Otherwise you have to punch about five or six holes, eh, take you all day to set one net. You get two holes, eh, a string and a hook then the trout gets caught together. Then pull it out one, tie a rope on the other side and take your trout out, and your line, and your line, and tie a net onto it, and put it back in and the net is set.*
>
> Interviewer: *Is that a typical way of, Métis way of setting nets?*
>
> Participant: *Yeah, that's the way they used to do it. In fact, Dad's got a picture down here at the Northern, him and Phillipe … They got a big trout there. Cold there, they are all dressed up. I seen his picture down there.*
>
> Interviewer: *So did Indians fish like that too.*
>
> Participant: *Well, I guess the Métis taught them how to.*
>
> Interviewer: *(laughs) Because that's a pretty neat way of doing that, eh?*
>
> Participant: *Pretty neat way of doing it.*
>
> Interviewer: *Is that especially when the ice was really, really thick?*
>
> Participant: *Real thick, yeah … holy, the ice used to be thick. (TUS#52, 2001)*

Traditionally, seasonal weather conditions have not only been a critical factor in determining when species with year-round availability are harvested, but have driven the development and use of storage techniques. Interview participants shared cultural knowledge related to the selection and use of animal hides and duck feathers to fashion the warm clothing and bedding traditionally required to provide insulation against the anticipated cold of Arctic winters. For instance, they explained that winter caribou hide has longer hair that falls out too easily, and that summer hides with their shorter, denser fur are therefore better for providing warmth. Participants also recalled their parents saving the feathers from duck hunts to be used as down stuffing for comforters, pillows, and other bedding. As revealed in NSMA's interview transcripts, Métis traditional knowledge contains both practical knowledge of seasonal weather patterns and awareness of a gradual and consistent change in overall temperatures and associated conditions. Interview respondents suggested that before the middle of the twentieth century, there were comparatively fewer forest fires in the Northwest Territories, and that they were more often man-made, whereas during the second half of the century, fires were more likely caused by lightning. They also reported changes to fish habitat and movements as a result of both higher temperatures overall and warming temperatures earlier in the season:

One thing I have noticed for Pauline Bay area is these years we've had hot weather and the ice goes out early. The water really warms up a lot, so you're starting to catch pike out in Hearne Channel, which you never would get before. You'd find them in the shallow bays, maybe along the river there. But we're out trolling for trout in the deep water, we got one on, reeled it in and it was a big pike, and we'd never seen that before. I'd never seen it before… Think it just warmed up so much that they're able to just go out there. (TUS#694, 2015)

Based on their knowledge of the species they have harvested for generations and their preferred habitats, NSMA members also reported knowledge of changes to the health, behaviour, and distribution of wildlife as a result of warmer temperatures. Interview respondents observed that migration patterns for caribou had changed over the twenty years preceding the interviews, and they reported that caribou used to be fatter and the fat was distributed more evenly over the animals' backs, hips, bellies, and chests. In the following exchange, a Métis harvester described the northern migration of parasites, as a result of milder winters, and changes to caribou migration patterns and food sources due to increased forest fire activity:

Participant: *I'm starting to hear of some cases of, like, parasites on the outside of the moose, ticks, and I've seen that, where the moose gets like those big warts on them. I've seen a bit of that.*

Interviewer: *Ticks, eh, pretty far north.*

Participant: *Yeah, that was ticks. Yeah, that's bad news if it comes up here. Like Manitoba moose population has gone… taken a real nosedive because of those things, eh? Yeah, it's really hard on a moose. You start getting mild winters and it becomes a real problem.*

Interviewer: *Yeah. So do you see any change in the number of animals at all?*

Participant: *I think there's probably, it seems like there's more moose, although looking at my success in the last few years you wouldn't think so. But, yeah, I think a sort of observation of other people [is] … they see more moose, you know. When they are out flying or whatever.*

Interviewer: *And what about caribou?*

Participant: *Caribou I think they are about the same. But, you know, distribution changes like every year, where they will move into a different area. And I think, you know, that is starting to, with the pattern of fires that we've had and stuff, it could present some problems locally.*

Interviewer: *Yeah, people depend on that.*

Participant: *Yeah, we certainly got indications for the herds themselves, eh. They are starting to burn up all their forage out there. (TUS#81, 2001)*

North Slave Métis Alliance members also reported that warmer temperatures and changes to precipitation patterns and soil conditions were causing corresponding changes in the berries they had traditionally gathered:

I've seen a change in berries, yeah. Like, we've had bad weather. In the School Draw it was all development, totally destroyed all those berry beds down there. I find that the strawberries, not the strawberries but the raspberry bushes that we used to know and see around, the berries have gotten smaller, and they're always dusty for some reason, and they've dried up. I don't know, it's probably because of drought. Too hot and dry. And even the cranberries. Like, last year I thought it was going to have lots, but it was too hot and dry. I had no berries. The first year I was there I had lots of cranberries, but last I didn't have anything and this year I'm going to wait and see. Even off in the bush, when I would go walking off in the bush, no cranberries. I couldn't believe it! (TUS#5, 2001)

NSMA members described all of these climate change impacts in contrast to conditions that they expected to encounter based on their cultural knowledge. In this way, when Métis frame impacts, they also reveal cultural knowledge of baseline trends and expectations against which they set the impacts, as well as processes of knowledge change. Interview participants suggested that the climatic and environmental changes they observed had become considerations for them when evaluating the risks and benefits of development within their traditional territory:

You're also creating all these exits for gas, oil and gas. You create [exits] for methane gas to come out, add to the greenhouse gas in the atmosphere, which is not good. And they say that there is sufficient oil and gas on the books right now to take us well beyond the 2-degree temperature increase, which is the critical point. And they say that just the stuff that's on the books is up to six times more than what is needed to take us to that 2-degree increase. So it's quite the situation. Do we want to contribute to something like that? (TUS#694, 2015)

The NSMA's transcripts show that Métis cultural knowledge of climate change is rooted in applied knowledge of historical climatic and environmental conditions, including special practices related to these conditions, and in observation and analysis of recent and continual deviations from historical norms. Métis cultural knowledge suggests that in addition to the variability in weather and corresponding environmental conditions anticipated from year to year, climate change is producing an overall warming, with impacts on the health, behaviour, and distribution of fish and wildlife, which are related to impacts on seasonality, precipitation, water levels, and ice quality.

Conclusions

Environmental knowledge is central to Métis history insofar as it is the body of knowledge acquired through close association with traditional practices, which Métis individuals were often called upon to share in their frequent roles as middlemen. Warburton Pike's *The Barren Ground of Northern Canada*, provides a late-nineteenth-century snapshot of the importance of Métis knowledge related to climate and the environment, as demonstrated by his guide, King Beaulieu, and Beaulieu's kinsmen. As mentioned earlier, Pike's account of the party's route and decisions made along the way about when, where, and how to travel, shelter, harvest food, and gather supplies, revealed cultural knowledge held by his Métis companions. He also recorded Beaulieu's traditional stories, which are embedded with cultural knowledge of climate and environment, including awareness of seasonal and continual changes within both and indications of possible Métis knowledge regarding climatic and environmental change affecting animal behaviour.

The NSMA's interview transcripts are somewhat nuanced on the subject of changes to climate and the environment. They record knowledge of both continual changes in weather (i.e., variability in weather and corresponding environmental conditions from year to year), and also gradual but continual changes in temperatures and corresponding conditions over time (i.e., overall warming). Based on their knowledge of the species they have harvested for generations and their preferred habitats, NSMA members reported changes to the health, behaviour, and distribution of wildlife as a result of warmer temperatures. They reported changes to fish habitat and movements as a result of both higher temperatures overall and warming temperatures earlier in the season. They also described traditional Métis fishing techniques that were developed when "*the ice used to be thick*" but could no longer be practised due to environmental changes. NSMA members' observations of climate change impact, such as changes to the health, behaviour, and distribution of wildlife as a result of warmer temperatures, also revealed cultural knowledge related to climate and environment by contrasting these changes with the established norm their Métis cultural knowledge anticipated. In reporting, for example, changes to fish habitat and movements as a result of both higher temperatures overall and temperatures warming earlier in the season, participants may have also been indicating the ongoing refinement of Métis cultural knowledge related to climate and climate change. NSMA members' cultural knowledge of climate change is rooted in applied knowledge of historical climatic and environmental conditions, including special practices related to these conditions, and in observation and analysis of recent and continual deviations from historical norms. This cultural knowledge suggests that in addition to the variability in weather and corresponding environmental conditions anticipated from year to year, climate change is producing an overall warming, with impacts on the health, behaviour, and distribution of fish and wildlife, which are related to impacts on seasonality, precipitation levels, water levels, and ice quality.

References

Barr, S. 2010. Great Britain at Fort Rae, Canada. *In* The history of the international polar years (IPYs). pp. 59–63.

Bellman, J.L. and Hanks, C.C. 1998. Northern Métis and the fur trade. *In* Picking up the threads: Métis history in the Mackenzie Basin. Métis Heritage Association of the Northwest Territories and Parks Canada–Canadian Heritage. pp. 29–68.

Bulkeley, Rip. 2010. The first three polar years: A general overview. *In* The history of the international polar years (IPYs). pp. 1–6.

Downing, A. and Cuerrier, A. 2011. A synthesis of the impacts of climate change on the First Nations and Inuit of Canada. *Indian Journal of Traditional Knowledge* 10:57–70.

Duerden, F. 2004. Translating climate change impacts at the community level. *Arctic* pp. 204–212.

Franklin, J. 1828. Narrative of a second expedition to the shores of the Polar Sea in the years 1825, 1826, and 1827.

Guyot, M., Dickson, C., Paci, C., Furgal, C., and Chan, H.M. 2006. Local observations of climate change and impacts on traditional food security in two northern Aboriginal communities. *International Journal of Circumpolar Health* 65:403–415.

Hanks, C. 1999. Francois Beaulieu II: Son of the last coureurs de bois in the Far Northwest. Historic Sites and Monuments Board of Canada Agenda Paper.

Hanks, C. 2000. Francois Beaulieu II: The origins of the Métis in the Far Northwest. Prepared for Rupert's Land Colloquium 2000, Centre for Rupert's Land Studies, University of Winnipeg.

Hayden, S. 2008. Final report on the 2008 Old Fort Rae landscape archeology project. Prepared for the North Slave Métis Alliance.

Hayden, S. 2010. One land, many people: Archeology, agency, and landscape at Old Fort Rae, Northwest Territories.

Hinzman, L.D., Bettez, N.D., Bolton, W.R., Chapin, F.S., Dyurgerov, M.B., Fastie, C.L., Griffith, B., Hollister, R.D., Hope, A., Huntington, H. P., Jensen, A.M., Jia, G.J., Jorgenson, T., Kane, D.L., Klein, D.R., Kofinas, G., Lynch, A.H., Lloyd, A.H., McGuire, A.D., Nelson, F.E., Oechel, W.C., Osterkamp, T.E., Racine, C.H., Romanovsky, V.E., Stone, R.S., Stow, D.A., Sturm, M., Tweedie, C.E., Vourlitis, G.L., Walker, M.D., Walker, D.A., Webber, P.J., Welker, J.M., Winker, K.S., and Yoshikawa, K. 2005. Evidence and implications of recent climate change in northern Alaska and other Arctic regions. *Climatic Change* 72:251–298.

Hopper, J. F. 1985. Early meteorological observations at Fort Enterprise, Northwest Territories, Canada. *Polar Record* 22:684–688.

Houston, C. 2014. Arctic ordeal: The journal of John Richardson, surgeon-naturalist with Franklin, 1820–1822.

Hudson's Bay Company Archives, Archives of Manitoba, Government of Manitoba. Available from http://www.gov.mb.ca/chc/archives/hbca/index.html.

Johnson, L. 1975. The Great Bear Lake: Its place in history. *Arctic* 28:231–244.

Jones, G.C.D. 2005. Historical profile of the Great Slave Lake area's mixed European-Indian ancestry community. Prepared for Justice Canada.

Jones, G.C.D. 2014. Research report, phase I and II: Historic Métis populations north of Great Slave Lake. Prepared for North Slave Métis Alliance.

McCormack, P.A. 2011. The ethnogenesis of the northern Métis of the Great Slave Lake area. Prepared for North Slave Métis Alliance.

Meteorological Council of Great Britain. 1879. Contributions to our knowledge of the meteorology of the Arctic regions. Her Majesty's Stationery Office.

National Oceanic and Atmospheric Administration (NOAA) Arctic Research Office. Daily mean surface air temperature and sea-level pressure, Fort Rae, the first International Polar Year 1882–1883. NOAA, University of Washington. Available from http://www.arctic.noaa.gov/aro/ipy-1/Data-S8.htm.

North Slave Métis Alliance. 2013. Traditional knowledge and land use report: A study for De Beers Canada Inc. proposed Gahcho Kué project.

Northwest Territories Environment and Natural Resources. 2008. NWT climate change and adaptation report.

Pike, W. 1892. The barren ground of northern Canada.

Province of Manitoba. 2015. Spotlight: HBC in words and images. Hudson's Bay Company Archives. Available from http://www.gov.mb.ca/chc/archives/hbca/spotlight/knights_tale.html.

Przybylak, R. and Vizi, Z. 2005. Air temperature changes in the Canadian Arctic from the early instrumental period to modern times. *International Journal of Climatology* 25:1507–1522.

Riedlinger, D. and Berkes, F. 2001. Contributions of traditional knowledge to understanding climate change in the Canadian Arctic. *Polar Record* 37:315–328.

Stevenson, M. 2000. Old Fort Rae's "Old Fort": An early Métis settlement on Great Slave Lake, preliminary excavations.

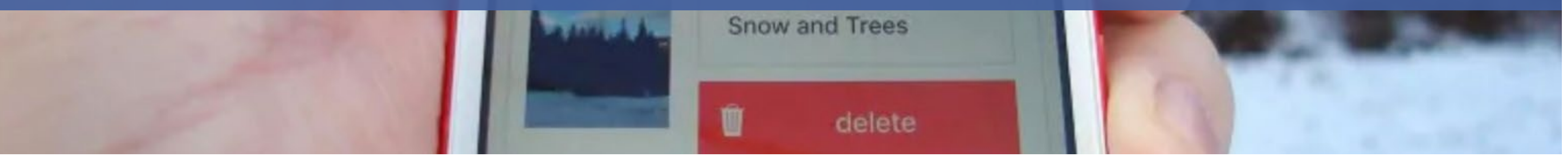
Stevenson, M. 2001. The North Slave Métis land use report (Draft). Prepared for North Slave Métis Alliance.

Tam, B.Y., Gough, W.A., Edwards, V., and Tsuji, L.J. 2013. The impact of climate change on the lifestyle and well-being of a First Nation community in the western James Bay region. *Canadian Geographer* 57:441–456.

Thomson, A. 1948. The growth of meteorological knowledge of the Canadian Arctic. *Arctic* 1:34–43.

Wood, K. and Overland, J.E. 2006. Climate lessons from the first International Polar Year. *Bulletin of the American Meteorological Society*, v. 87.

A PROFILE OF THE ENUK ENVIRONMENT AND HEALTH MONITORING PROGRAM



Amy Kipp[1*], Ashlee Cunsolo[2], Daniel Gillis[3], Alexandra Sawatzky[1], Oliver Cook[3], Nic Durish[3], Inez Shiwak[4], Charlie Flowers[4], Rigolet Inuit Community Government[4], Marilynn Wood[5], and Sherilee L. Harper[1,6]

[1] *Department of Population Medicine, University of Guelph, Guelph, Ontario, Canada*

[2] *School of Computer Science, University of Guelph, Guelph, Ontario, Canada*

[3] *The Labrador Institute, Memorial University, Happy Valley - Goose Bay, Newfoundland and Labrador, Canada*

[4] *The Rigolet Inuit Community Government, Rigolet, Newfoundland and Labrador, Canada*

[5] *Department of Health and Social Development, Nunatsiavut Government, Happy Valley - Goose Bay, Newfoundland and Labrador, Canada*

[6] *School of Public Health, University of Alberta, Edmonton, Alberta, Canada*

* *akipp@uoguelph.ca*

The eNuk Environment and Health Monitoring Program (eNuk) is being led by Inuit researchers from Rigolet, Nunatsiavut, Labrador, in partnership with researchers at the University of Guelph, the Labrador Institute of Memorial University, the University of Alberta, and the Nunatsiavut Department of Health and Social Development. The study area consists of the area in and around the community of Rigolet, in the Labrador Inuit Settlement Area known as Nunatsiavut.

Abstract

Impacts of climate change in Northern Canada present major challenges for the health of humans and the environment, with many of the most acute impacts experienced among Indigenous peoples such as Inuit, throughout Inuit Nunangat. Although research has identified associations of climatic and environmental change with human health outcomes, detecting and responding to these outcomes is a significant challenge. Comprehensive, integrated, sustainable, and locally appropriate monitoring systems have been identified as one potential strategy to meet this complex challenge. In this article, we present an example of this type of monitoring, the eNuk program, which is a participatory, Inuit-led environment and health monitoring program in Rigolet, Nunatsiavut, Labrador. An integral part of the program is a mobile application (the eNuk app), which Inuit can use to track, analyze, and respond to environmental and health changes related to climate change. To conceptualize and develop the eNuk app, a variety of methods were used: focus group discussions and semi-structured interviews with community members and government representatives, two systematic literature reviews, an environmental scan of existing monitoring apps in the Circumpolar North, participatory development of the eNuk app through community open houses and consultations, and pilot testing of the eNuk app. Through these methods, the eNuk program has emerged as a comprehensive, Inuit-led monitoring system, which can be used to develop locally appropriate programming and policy in the region and provide management tools for decision makers and communities that are grounded in and guided by Inuit values, knowledge, and science.

Suggested citation:

Kipp, A., Cunsolo, A., Gillis, D., Sawatzky, A., Cook, O., Durish, N., Shiwak, I., Flowers, C., Rigolet Community Government, Wood, M., and Harper, S.L. 2018. A profile of the eNuk environment and health monitoring program. Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 117–125. DOI: 10.35298/pkc.2018.14*

Introduction

Impacts of climate change in Northern Canada present major challenges for the health of humans and the environment, with the most acute impacts experienced among Indigenous peoples such as Inuit, throughout Inuit Nunangat (Cunsolo Willox et al. 2013; Furgal and Seguin 2006). Research has uncovered many negative associations of climatic and environmental change with human health outcomes, including morbidity and mortality due to rising temperatures and extreme weather events (Ford et al. 2006; Furgal and Seguin 2006; Pearce et al. 2010); diminished food and water security (Goldhar, Bell, and Wolf 2014; Harper et al. 2015a, 2015b; Organ et al. 2014); increased incidences of food-borne, water-borne, and vector-borne disease (Harper et al. 2011, 2015a, 2015b; Martin et al. 2007); and impacts on mental health and well-being due to displacement of people, loss of livelihoods and cultural identity, and changing relationships with the land and culturally significant natural places (Cunsolo Willox et al. 2012, 2013a, 2013b, 2015). Detecting and responding to these outcomes to support human health is a serious challenge.

To monitor and respond to these shifts in Inuit health and environment, government representatives, health practitioners, and academics are calling for comprehensive, integrated, sustainable, and locally appropriate monitoring programs (Jay and Marmot 2009; Haines et al. 2006; Ford 2012). To meet this call, a team of Inuit and non-Inuit researchers have been working with the Inuit community of Rigolet, Nunatsiavut (Fig. 1), to conceptualize, develop, and implement the eNuk program (Harper et al. 2016; Sawatzky et al. 2017a). The eNuk program is an Inuit-led participatory environment and health monitoring program intended to support Inuit efforts to track, analyze, and respond to the environmental and health impacts of climate change in Rigolet (Harper et al. 2016; Sawatzky et al. 2017a). The program involves supporting and extending existing research capacity in the community, as well as developing innovative monitoring tools. A foundational component of the eNuk program is the eNuk mobile application (eNuk app), a tool which will provide an opportunity for community members to record and share their observations of environmental and health indicators of climate change through a variety of multimedia while in the community and on the land (Harper et al. 2016; Sawatzky et al. 2017a, 2017b).

The eNuk program was developed using a community-led and participatory design research approach, involving collaboration with community research leads in Rigolet, the Rigolet Inuit Community Government, the Nunatsiavut Department of Health and Social Development, and academic researchers at the University of Guelph, the Labrador Institute of Memorial University,[1] and the University of Alberta (Harper et al. 2016; Sawatzky et al. 2017a, 2017b). This paper provides a summary of the eNuk program, detailing the methods used to co-create and develop the monitoring program and the eNuk app more specifically (Fig. 2), as well as identifying emergent themes. This research highlights the need for (1) integrated environmental and health monitoring and (2) community participation in all aspects of monitoring programs. Moreover, this profile paper emphasizes the potential benefits of such monitoring for community and regional adaptation strategies and policy decision-making in the face of rapidly changing climatic conditions in the North.

Conceptualizing the eNuk program

For a decade, the community of Rigolet, Nunatsiavut (population 305; 95% identifying as Inuit), has been a leader in climate change and health research in the North. With research ranging from climate change impacts on food security (Harper et al. 2015c; Cunsolo Willox 2013b), the incidence of water-borne disease and acute gastrointestinal illness (Harper et al. 2011, 2015a, 2015b; Wright et al. 2017), mental health (Cunsolo Willox 2012, 2013a, 2013b), and cultural continuity (Cunsolo et al. 2017; Petrasek MacDonald et al. 2013a, 2013b). Rigolet has been actively leading and initiating research to understand the varying ways that warming temperatures, changing weather patterns, decreasing ice coverage and extent, and shifting plant and animal patterns are impacting Inuit health. Beyond the importance and usefulness of this research to supporting Inuit health, it was identified that in order to provide more timely and usable information, research on climate change and health in the community needed to move from climate-health documentation to response.

1 *The Labrador Institute is a division of Memorial University.*

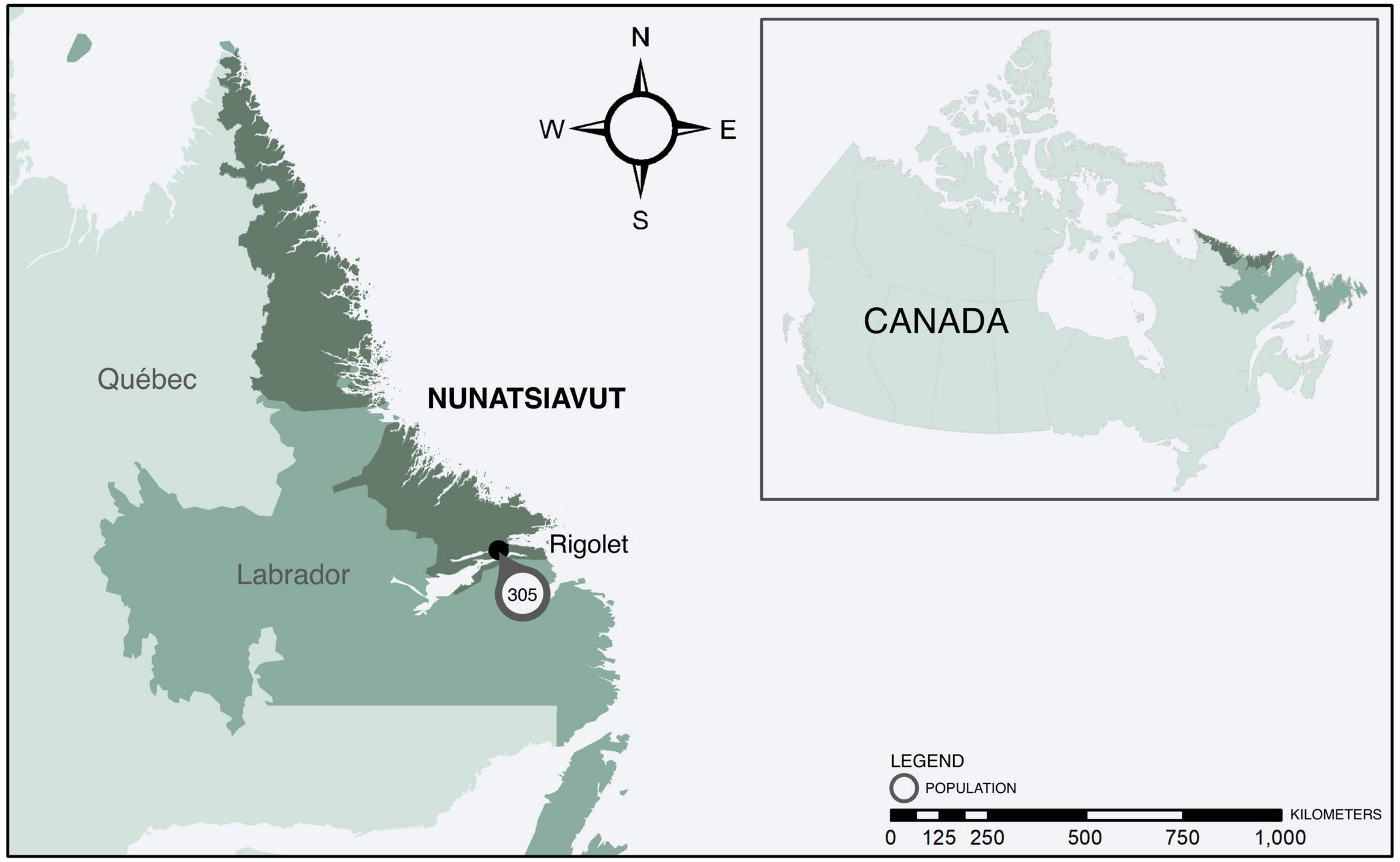


Figure 1: Map of Nunatsiavut, indicating location and population of Rigolet.

In 2013, the initial concept of the eNuk program emerged from discussions with various members of the Rigolet Inuit Community Government, the Nunatsiavut Department of Health and Social Development, and researchers across different academic institutions about how to monitor and respond to the environmental and health impacts of climate change. From these initial discussions, the team wrote grant applications to fund the development of a community-based monitoring program, including an Inuit-specific app to enhance monitoring of changes in the land, waters, weather, plants, and animals (e.g., changes to ice thickness, warmer temperatures, increased prevalence of extreme weather events, changes to the presence and condition of flora and fauna), and associated impacts to physical, mental, emotional, and spiritual health and well-being (e.g., feelings of anxiety associated with unpredictable weather patterns, injury due to entrapment in unseasonably thin ice conditions).

To begin the design phase of the eNuk program, based on Inuit perspectives on environmental and health monitoring, and to situate this work within existing activities related to integrated and community-based monitoring in the North, several methods were used to engage people, seek input, understand needs and priorities, and support/enhance local capacity for research; herein, we outline examples of these activities.

Beginning in 2015, 31 interviews were conducted with individuals in and around Rigolet and Happy Valley - Goose Bay, Labrador, with community members (n=13), local and regional government representatives (n=14), and healthcare professionals (n=4), as well as several focus group discussions. Open-ended questions focused on what environmental and health conditions were important to monitor in Rigolet, why they were important to monitor, and how monitoring should be done, thereby supporting continued Inuit leadership and guidance.

To contextualize the eNuk program within the broader research literature on integrated environment-health monitoring in the Circumpolar North, a systematic realist review was conducted. MEDLINE® and Web of Science™ databases were systematically searched to identify

Figure 2: Methods used to design the eNuk program and develop eNuk the app, 2014–2018.

relevant articles. Following a realist approach, questions were asked regarding how, why, and in what contexts integrated monitoring systems were discussed (Pawson et al. 2005; Braun and Clarke 2006). Key components of integrated environment and health monitoring systems were identified and characterized.

An environmental scan (Arksey et al. 2005; Mew et al. 2017; Pham et al. 2014) of community-based monitoring programs in the Circumpolar North was conducted to further contextualize and situate the eNuk program within already ongoing monitoring programs. Several methods, including academic consultation, participation in two workshops on community-based participatory monitoring in the North, searches of grey and peer-reviewed literature, and searches of an online database of monitoring programs,[2] were used to identify initiatives working with Indigenous communities and using web-based technology (e.g., smartphone apps or web-based databases). Information about these programs was organized based on characteristics of the program and indicators they monitored.

Developing the eNuk app

To ensure the eNuk app was developed to meet community needs, and was both useful and timely, a participatory design approach was central to its development.[3] This approach, which used a variety of methods, allowed for community members and the research team to co-develop and co-design app features and functionality (Sanoff 2008; Simonsen et al. 2012; Racadio et al. 2014).

2 *The Atlas of Community-Based Monitoring and Indigenous Knowledge in a Changing Arctic is an online atlas developed to highlight and compile community-based monitoring throughout the Circumpolar North.*

3 *For more information on participatory design, see Sanoff 2008; Simonsen et al. 2012; and Racadio et al. 2014.*

In October 2015 and February 2016, a series of in-depth, semi-structured, conversational interviews were conducted with community members to assess the technological resources available in Rigolet, identify what technical components community members wished to see incorporated into the app, and determine who was interested in having an active role in app design and evaluation. Additionally, throughout the app design process, a series of eight well-attended open houses were held between 2015 and 2017 to encourage community input, participation, and engagement. For example, several interactive activities at each open house allowed community members to contribute to the co-design of the eNuk app through such activities as participatory mapping, paper prototyping of the app interface, and ranking priorities. Several classroom workshops were hosted at the Northern Lights Academy to further engage youth in co-development of the app (Robertson and Simosen 2018).

In 2016, a prototype of the eNuk app was complete, and it was piloted in five Rigolet households. The pilot households had been identified by the community research leads and reflected a diversity in gender, age, livelihood, and land experience. Through the technology and community leads, evaluation of the prototype was ongoing, and the experiences of these pilot-users contributed to an updated version of the eNuk app, to be released in the summer of 2018.

At the time this paper was written (March 2018), another series of semi-structured interviews were being led by community research leads (n=8). These interviews were designed to provide Rigolet Inuit with the opportunity to identify and characterize specific environment and health indicators that should be monitored by the eNuk app (e.g., indicators related to ice, snow, rain, wind, tide, temperature, wildlife, vegetation, drinking water, and

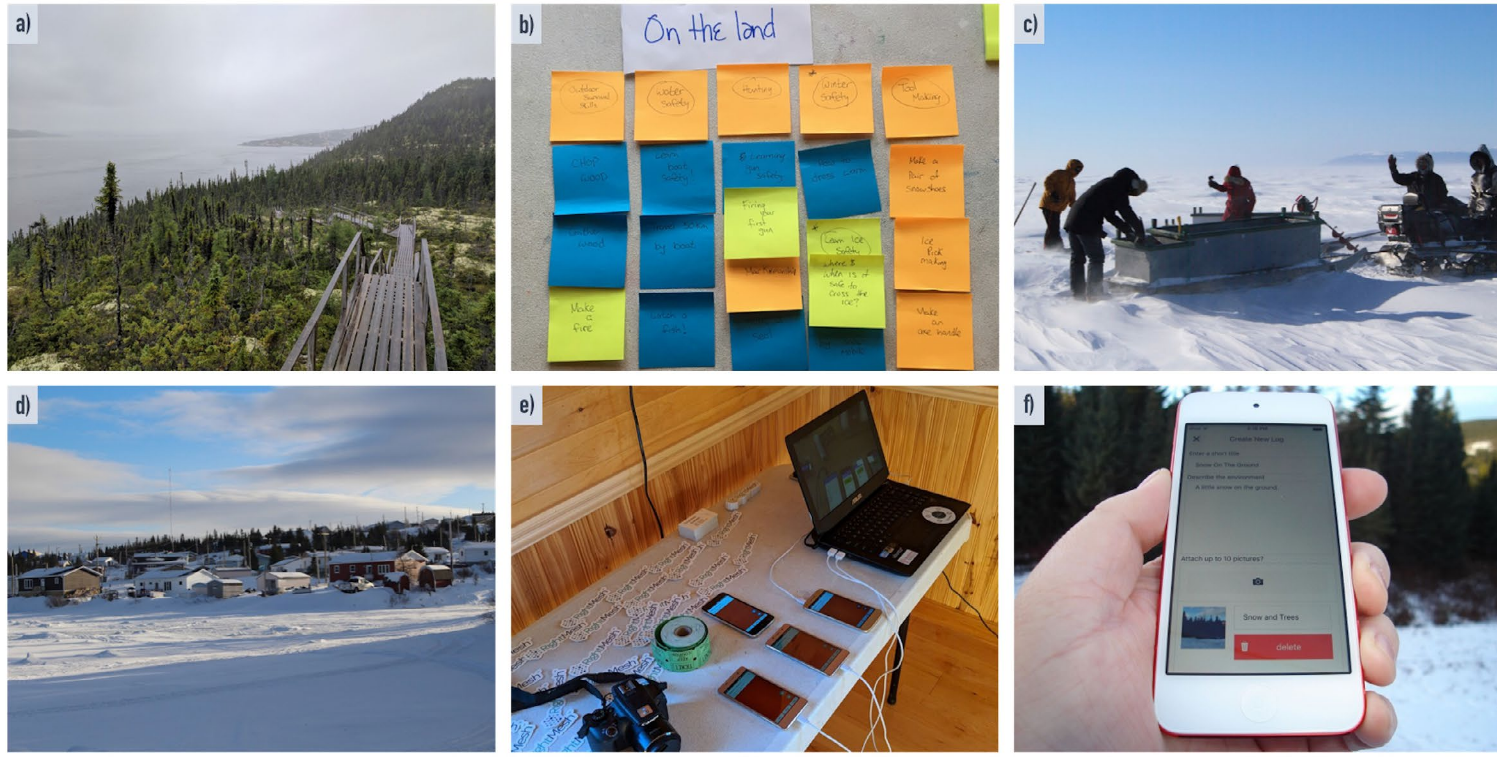


Figure 3: Images of Rigolet and the different stages of the eNuk program: (a) view from the boardwalk stretching from Rigolet to key historic and archaeological sites in the region, (b) participatory post-it-note method used when consulting community members about app design, (c) the eNuk research team testing out technical equipment with community partners on English River in –40°C conditions, (d) view of houses in the community of Rigolet during wintertime, (e) booth for the eNuk app at a community open house, and (f) the pilot version of the eNuk app.

mental wellness) and to describe how the app could best capture data related to these indicators. Initial analysis of the interviews found that Inuit described environmental information that is used for decision-making on the land and in the community, the sources and the sharing of this environmental information, and connections between changes in certain environmental conditions and community health. Inuit insights from these interviews will contribute to the development of updates for the app.

Integrated environment and health monitoring

During the eNuk program and app co-development, several themes emerged. Through the semi-structured interviews, a variety of specific environment and health indicators were categorized by Inuit, including freshwater conditions; sea ice and trail conditions; trends in plants, animals, and wildlife; changing weather, temperature, and climate patterns; and increased anxiety and depression among community members (Sawatzky et al. 2017a). Beyond these indicators, Inuit discussed community priorities for the eNuk program, including the promotion of environmental stewardship, cultural knowledge, and evidence-based decision-making (Sawatzky et al. 2017a). These priorities highlight the importance of land for Inuit conceptualizations of well-being, and the need to develop the eNuk program in a holistic way, led by Inuit ways of knowing (Harper et al. 2016; Sawatzky et al. 2017a). An integrated approach to an environment-health monitoring program is therefore in line with Inuit understandings of the health impacts of climate change in Rigolet (Sawatzky, et al. 2017b).

Furthermore, we found that to respond to environmental change, programs need to consider numerous sources of information, multiple stressors, wide geographic coverage, and different knowledge systems (Sawatzky et al. 2017c). The importance of community co-designed and co-developed technology has also become increasingly clear. Community-led and community-designed monitoring ensures community needs are met, and enables robust and authentic environmental and health data collection that can inform research, policy, programming, and decision-making (Sawatzky et al. 2017c).

The importance of participatory and community-led research and design

A community-led approach used throughout the eNuk program, including the co-development of the app, has ensured Inuit knowledge, values, and expertise are reflected in the monitoring program. Indeed, through the participatory methods highlighted herein, the eNuk program has been and continues to be developed as culturally relevant and useful for community members (Sawatzky et al. 2017a, 2017b).

Conclusion

Through community-led research and participatory co-design, the eNuk program is facilitating locally appropriate, integrated environment-health monitoring. The process of conceptualizing and co-developing the eNuk program has highlighted several potential lessons for researchers as well as policy and decision makers in Northern Canada, including

- the importance of Inuit-led and co-designed programs;
- the power of using Inuit-identified indicators and incorporating Indigenous understandings of wellness in monitoring programs;
- the need for integrated monitoring programs that are context-specific and culturally relevant; and
- the usefulness of innovative technology (e.g., apps) that is designed by and for Inuit as a tool for monitoring programs.

The eNuk program is an example of an Inuit-led monitoring system that could inform locally appropriate programming in Rigolet, as well as the region, providing management tools for decision makers and communities that are grounded in and guided by Inuit values, knowledge, and science. This type of monitoring program has the potential to strengthen resilience to environmental change while directing future adaptation responses in the region and across the North.

Community considerations

The eNuk program is premised on community participation and leadership. Through the eNuk app, community members in Rigolet, Nunatsiavut, will be able to monitor the health and environmental impacts of climate change in and around their communities, promoting the collecting and sharing of important community information. In this way, the eNuk program supports community-level adaptation to environmental change.

Acknowledgements

This research takes place in the ancestral and continued homelands of Inuit in the Labrador Inuit Settlement Area known as Nunatsiavut. The eNuk research team would like to thank the community of Rigolet for its invaluable leadership and insight on the project, as well as Polar Knowledge Canada, the Canadian Internet Registration Authority, the Canadian Institutes for Health Research, and the Natural Sciences and Engineering Research Council of Canada for their funding support. The team would like to give special thanks to Charlotte Wolfrey of Rigolet for her early visions of the eNuk program and for her continued guidance, wisdom, and support.

References

Arksey, H. and O'Malley, L. 2005. Scoping studies: Towards a methodological framework. International *Journal of Social Research Methodology* 8:19–32.

Bano, M. and Zowghi, D. 2013. User involvement in software development and system success: A systematic literature review. *In* Proceedings of the 17th International Conference on Evaluation Assessment in Software Engineering (EASE 2013). pp. 125–130.

Björgvinsson, E., Ehn, P., and Hillgren, P. 2012. Design things and design thinking: Contemporary participatory design challenges. *Design Issues* 28:101–116.

Braun, V. and Clarke, V. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3:77–101.

Cunsolo Willox, A., Harper, S.L., Edge, V.L., Landman, K., Houle, K., Ford, J.D., and Rigolet Inuit Community Government. 2013a. The land enriches the soul: On climatic and environmental change, affect, and emotional health and well-being in Rigolet, Nunatsiavut, Canada. *Emotion, Space, and Society* 6:14–24.

Cunsolo Willox, A., Harper, S.L., Ford, J.D., Edge, V.L., Landman, K., Houle, K., Blake, S., and Wolfrey, C. 2013b. Climate change and mental health: An exploratory case study from Rigolet, Nunatsiavut, Canada. *Climatic Change* 121:255–270.

Cunsolo Willox, A., Harper, S.L., Ford, J.D., Landman, K., Houle, K., Edge, V.L., and Rigolet Inuit Community Government. 2012. "From this place and of this place": Climate change, sense of place, and health in Nunatsiavut, Canada. *Social Science & Medicine* 75:538–547.

Cunsolo, A., Shiwak, I., Wood, M., and IlikKuset-Ilingannet team. 2017. "You need to be a well-rounded cultural person": Youth mentorship programs for cultural preservation, promotion, and sustainability in the Nunatsiavut region of Labrador. *In* Northern sustainabilities: Understanding and addressing change in the circumpolar world. Springer, Cham. pp. 285–303.

Cunsolo Willox, A., Stephenson, E., Allen, J., Bourque, F., Drossos, A., Elgaroy, S., Kral, M., Mauro, I., Moses, J., Pearce, T., Petrasek MacDonald, J., and Wexler, L. 2015. Examining relationships between climate change and mental health in the Circumpolar North. *Regional Environmental Change* 15:169–182.

Ford, J.D., Smith, B., and Wandel, J. 2006. Vulnerability to climate change in the Arctic: A case study from Arctic Bay, Canada. *Global Environmental Change* 16:145-160.

Ford, J.D. 2012. Indigenous health and climate change. *American Journal of Public Health* 102:1260–1266.

Furgal, C. and Seguin, J. 2006. Climate change, health, and vulnerability in Canadian northern Aboriginal communities. *Environmental Health Perspectives* 114:1964–1970.

Gearheard, S., Aporta, C., Aipellee, G., and O'Keefe, K. 2011. The Igliniit project: Inuit hunters document life on the trail to map and monitor Arctic change. *The Canadian Geographer / Le Géographe canadien* 55:42–55.

Goldhar, C., Bell, T., and Wolf, J. 2014. Vulnerability to freshwater changes in the Inuit Settlement Region of Nunatsiavut, Labrador: A case study from Rigolet. *Arctic* 67:71–83.

Haines, A., Kovats, R.S., Campbell-Lendrum, D., and Corvalan, C. 2006. Climate change and human health: Impacts, vulnerability, and public health. *Public Health* 120:585–596.

Harper, S.L., Cunsolo, A., Shiwak, J., Shiwak, I., Flowers, C., Wood, M., Gillis, D., Ford, J., Furgal, S., Sawatzky, A., and Cook, O. 2016. Implementing a community-driven environment and health surveillance program with Inuit in Rigolet, Nunatsiavut. Open Access Government.

Harper, S.L., Edge, V.L., Ford, J., Thomas, M.K., IHACC Research Group, Rigolet Inuit Community Government, and McEwen, S.A. 2015a. Lived experience of acute gastrointestinal illness in Rigolet, Nunatsiavut: "Just suffer through it." *Social Science & Medicine* 126:86–98.

Harper, S.L., Edge, V.L., Ford, J., Thomas, M.K., Pearl, D.L., Shirley, J., IHACC Research Group, Rigolet Inuit Community Government, and McEwen, S.A. 2015b. Acute gastrointestinal illness in two Inuit communities: Burden of illness in Rigolet and Iqaluit, Canada. *Epidemiology & Infection* 143:3048–3063.

Harper, S.L., Edge, V.L., Ford, J., Willox, A.C., Wood, M., IHACC Research Group, Rigolet Inuit Community Government, and McEwen, S.A. 2015c. Climate-sensitive health priorities in Nunatsiavut, Canada. *BMC Public Health* 15:605.

Harper, S.L., Edge, V.L., Schuster-Wallace, C.J., Berke, O., and McEwen, S.A. 2011. Weather, water quality, and infectious gastrointestinal illness in two Inuit communities in Nunatsiavut, Canada: Potential implications for climate change. *EcoHealth* 8:93–108.

Jay, M. and Marmot, M. 2009. Health and climate change. *British Medical Journal* 339:645–646.

Martin, D., Bélanger, D., Gosselin, P., Brazeau, J., Furgal, C., and Déry, S. 2007. Drinking water and potential threats to human health in Nunavik: Adaptation strategies under climate change conditions. *Arctic* 60:195–202.

Mew, E.J., Ritchie, S.D., VanderBurgh, D., Beardy, J.L., Gordon, J., Fortune, M., Mamakwa, S., and Orkin A.M. 2017. An environmental scan of emergency response systems and services in remote First Nations communities in Northern Ontario. *International Journal of Circumpolar Health* 76:132–208.

Organ, J., Castleden, H., Furgal, C., Sheldon, T., and Hart, C. 2014. Contemporary programs in support of traditional ways: Inuit perspectives on community freezers as a mechanism to alleviate pressures of wild food access in Nain, Nunatsiavut. *Health and Place* 30:251–259.

Pals, N., Steen, M., Langley, D., and Kort, J. 2008. Three approaches to take the user perspective into account during new product design. *International Journal of Innovation Management* 12:275–294.

Pawson, R., Greenhalgh, T., Harvey, G., and Walshe, K. 2005. Realist review: A new method of systematic review designed for complex policy interventions. *Journal of Health Services Research & Policy* 10:21–34.

Pearce, T., Smit, B., Dierden, F., Ford, J., Goose, A., and Kataoyak, F. 2010. Inuit vulnerability and adaptive capacity to climate change in Ulukhaktik, Northwest Territories, Canada. *Polar Record* 46:157–177.

Petrasek MacDonald, J., Harper, S.L., Willox, A.C., Edge, V.L., and Rigolet Inuit Community Government. 2013a. A necessary voice: Climate change and lived experiences of youth in Rigolet, Nunatsiavut, Canada. *Global Environmental Change* 23:360–371.

Petrasek MacDonald, J., Ford, J.D., Willox, A.C., and Ross, N.A. 2013b. A review of protective factors and causal mechanisms that enhance the mental health of Indigenous circumpolar youth. *International Journal of Circumpolar Health* 72:21775.

Pham, M.T., Rajić, A., Grieg, J.D., Sargeant, J.M., Papadopoulos, A., and McEwen, S.A. 2014. A scoping review of scoping reviews: Advancing the approach and enhancing the consistency. *Research Synthesis Methods* 5:371–385.

Racadio, R., Rose, E., and Kolko, B. 2014. Research at the margin: Participatory design and community-based participatory research. *In* Proceedings of the 13th participatory design conference: Short papers, industry cases, workshop descriptions, doctoral consortium papers, and keynote abstracts. ACM, New York. pp. 49–52.

Robertson, T. and Simonsen, J. 2018. Challenges and opportunities in contemporary participatory design. *Design Issues* 28:3–9.

Sanoff, H. 2008. Multiple views of participatory design. *International Journal of Architectural Research* 2:131–143.Sawatzky, A., Cunsolo, A., Gillis, D., Shiwak, I., Flowers, C., Cook, O., Wood, M., Rigolet Inuit Community Government, and Harper, S.L. 2017a. Profiling the eNuk program. *Northern Public Affairs*.

Sawatzky, A., Cunsolo, A., and Harper, S.L. 2017b. The eNuk program: Developing a community-based, participatory health and environment surveillance strategy. Open Access Government.

Sawatzky, A., Cunsolo, A., Jones-Bitton, A., Middleton, J., and Harper, S.L. 2017c. Integrated environment and health surveillance: A systematic realist review. *In* Proceedings of the 2017 International Arctic Change Conference (ArcticNet 2017). p. 129.

Simonsen, J. and Robertson, T. 2012. Routledge international handbook of participatory design.

Wright, C.J., Sargeant, J.M., Edge, V.L., Ford, J.D., Farahbakhsh, K., Rigolet Inuit Community Government, Shiwak, I., Flowers, C., Harper, S.L., and IHACC research team. 2017. Water quality and health in northern Canada: Stored drinking water and acute gastrointestinal illness in Labrador Inuit. *Environmental Science and Pollution Research* pp. 1–13. doi:10.1007/s11356-017-9695-9.

RENEWABLE ENERGY ATLAS AND MICROGRID FIELD TESTING IN THE ARCTIC

Yves Poissant[1 *], Alexandre Côté[1], Naveen Goswamy[1], Robert Cooke[2], and Matt Wallace[3]

[1] Natural Resources Canada CanmetENERGY–Varennes, Varennes, Québec, Canada

[2] Polar Knowledge Canada, Whitehorse, Yukon, Canada

[3] Polar Knowledge Canada, Cambridge Bay, Nunavut, Canada

** yves.poissant@canada.ca*

The Renewable Energy Atlas and Microgrid Field Testing in the Arctic project is being led by National Resources Canada CanmetENERGY–Varennes. It is supported logistically by Polar Knowledge Canada, with the study area comprising several Inuit-owned business sites and Government of Nunavut sites. The study area is located in Cambridge Bay, Nunavut.

Abstract

In order to increase the contribution of renewable energy to local electricity generation mix in remote communities, more information about renewable energy resources in the Arctic (wind speed and solar irradiance) and the electrical load profiles of communities needs to be acquired so that renewable energy systems can be appropriately sized to meet demand. With that in mind, Natural Resources Canada (NRCan) CanmetENERGY, in collaboration with Polar Knowledge Canada (POLAR), developed a project proposal for ecoENERGY Innovation Initiative (ECO-EII) funding with the following objectives:

1. Development of a pan-Arctic Renewable Energy Atlas. This project has been proposed by the Arctic Council and is being supported by the Government of Canada, predominantly through NRCan CanmetENERGY–Ottawa;
2. Field testing of a renewable energy microgrid with intelligent load management in Cambridge Bay, with POLAR conducting the fieldwork under the guidance of NRCan CanmetENERGY–Varennes; and
3. A techno-economic assessment of renewable microgrid design to include a comparative study of optimal storage methods.

The cumulative efforts of these three phases will play a major role in helping to reduce dependence on high-cost, imported diesel fuel as a means of energy generation in remote northern communities. This proposal was accepted for full project funding through the ECO-EII program; . This report primarily focuses on the work conducted to date on Phase 2, field testing of a renewable energy microgrid with intelligent load management in Cambridge Bay.

Suggested citation:

Poissant, Y., Côté, A., Goswamy, N., Keyte, L., Cooke, R., and Wallace, M. 2018. Renewable Energy Atlas and Microgrid Field Testing in the Arctic. Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 126–130. DOI: 10.35298/pkc.2018.15*

Introduction

Canada's northern regions of Yukon Territory, the Northwest Territories, Nunavut, Nunatsiavut, and Nunavik are home to a population of 119,000 inhabitants who are scattered among 65 remote, rural communities. Many of these communities are highly dependent on diesel-based electricity generation, which ties a community like Cambridge Bay to electricity generation costs considerably higher than the Canadian average on a per-kilowatt-hour (kWh)[1] basis, with unsubsidized rates as high as $1.14 per kWh, compared with $0.132 in Ontario.[2] The logistics of routing diesel to such communities constitute one of the main reasons for the high cost of fuel. In addition, infrastructure for trucking and for fuel storage must be in place, increasing considerably the environmental impact of electricity generation in remote communities.

Ambient and climatic conditions such as extended solar irradiance in spring and summer months, colder winter temperatures that increase conductivity, and stronger, more frequent winds, particularly during winter months, provide the potential for increased use of clean, renewable energy from wind and photovoltaic (PV) systems. This would allow greater energy independence for many remote, off-grid communities such as Cambridge Bay, with a significant reduction in fossil-fuel usage.

It is not, however, a simple matter of replacing diesel generation with a renewable source. It is necessary to know what the energy loads are in a community — when energy demand peaks, when troughs occur, how those peaks and troughs correlate to renewable energy resource availability, and what the maximum amount of renewable energy that can be placed onto a microgrid is before that renewable resource has an impact on grid stability. Through the ECO-EII, NRCan CanmetENERGY–Varennes in partnership with NRCan CanmetENERGY–Ottawa and POLAR developed a three-phase project proposal to determine the potential for reducing diesel dependence for energy generation in remote northern communities. The overall project is entitled Renewable Energy Atlas and Microgrid Field Testing in the Arctic (REMFTA). The project will achieve its stated objectives by (1) improving access to renewable energy information by populating a pan-Arctic renewable energy atlas; (2) community monitoring, managing, and field testing of a renewable energy microgrid with intelligent load management in Cambridge Bay; and (3) collaborating with CanmetENERGY experts to study renewable energy integration with secondary storage methods.

This combined approach will offer insight into properly sizing wind and PV systems to accommodate common demand-side and ambient-based variability. This project aligns with two of POLAR's science and technology priorities; in particular, reducing diesel dependency for energy generation through greater uptake of Alternative and Renewable Energy and Improving the Design of Northern Build Infrastructure by identifying better building design, construction techniques, maintenance practices, technologies, and energy efficiencies for northern climates. As a co-lead on the ECO-EII project, POLAR is providing in-community advice and support, community liaison, project execution, and data collection.

REMFTA proposal

The original project proposal that was approved for NRCan ECO-EII funding has three distinct phases:

Arctic Renewable Energy Atlas: In collaboration with the Arctic Council's Sustainable Development Working Group (SDWG), CanmetENERGY–Ottawa is assisting in the development and population of the online Arctic Renewable Energy Atlas, a comprehensive toolkit that will include maps, renewable energy resources, and case studies of renewable energy projects across all eight Arctic member states. This toolkit will act as a database for renewable energy projects across the Arctic and provide researchers and potential project practitioners with access to resource knowledge and best practice. POLAR has served in an advisory role as needed.

Techno-economic assessment of renewables microgrid design and operation with load management in Alaska and Nunavut: A collaborative partnership between CanmetENERGY, POLAR, and Intelligent Energy Systems (IES) to develop a comparative study of renewable energy integration, coupled with secondary energy storage, through demand management and lithium-ion storage systems for remote microgrids in Alaska and Canada. This activity will gather and process data from Alaska's Chaninik Wind–Electric Thermal Storage (ETS) project, build ETS and battery system models using data from Alaska-based systems, and conduct a comparative

1 https://www.qec.nu.ca/sites/default/files/qec_energy_framework_-_generation_-_april_18_eng.pdf
2 https://www.oeb.ca/rates-and-your-bill/electricity-rates

techno-economic analysis of batteries and ETS for microgrid services for systems in Alaska and Canada. POLAR's role will be in managing the installation and monitoring the techno-economic assessment of the community's load usage and energy efficiency, and upon completion, sharing load-usage, energy-efficiency, and renewable energy findings with current and future community, government, and industry partners. This project will build on the work done under the community monitoring phase of the REMFTA proposal.

Community monitoring, managing, and testing of a renewable energy microgrid with intelligent load management in Cambridge Bay: This phase develops a coordinated approach to energy solutions (peak shaving, renewable energy integration), including the monitoring of renewable resources and community electrical demand. POLAR is managing the implementation of renewable energy monitoring and load-monitoring instrumentation in Cambridge Bay, collaborating with CanmetENERGY experts to study renewable energy integration with secondary storage methods through intelligent demand management, and developing open-source information sets and energy modelling. As this phase forms the main basis for this report, it will now be discussed in greater detail.

In order to ensure that the most representative data was obtained for this project, CanmetENERGY in collaboration with Nunavut's sole electrical energy utility, Qulliq Energy Corporation (QEC), developed a list of the top 21 high-energy-usage units in Cambridge Bay. Providing a community liaison function on behalf of the project, POLAR personnel visited the owners/occupiers of the aforementioned high-energy-usage locations to describe the purpose of the project, set out the potential benefits, and request their participation. This included providing project information to potential collaborating businesses, local government departments, and schools through a written summary that was prepared by NRCan CanmetENERGY–Varennes. The summary identified the goals of the project, the collaborating partners, the instrumentation that would need to be installed at each location, and any associated costs. POLAR personnel also conducted in-person discussions that centred on the value for the customer in attaining load profiles for daily, seasonal, and peak use operation. These benefits included how to make structural changes for greater energy efficiency as well as better overall methods for energy usage.

Following the initial in-person briefings, partnerships were established with ten commercial, public, and government locations in Cambridge Bay, including the elementary and secondary schools, the Canadian High Arctic Research Station (CHARS) main research building, the water treatment plant, and the northern store (a full list of locations is available upon request). Load-usage and energy-efficiency measures were then determined for each building within the set of collaborating partners by utilizing site surveys, reaching a better understanding of building function, and conducting qualitative load profiles based on hours of operation and equipment use as well as normal and peak load levels. Using this information, opportunities were evaluated to improve energy efficiency within the building envelope, and subsequently, internal equipment and current usage profiles. Using these energy audits, POLAR then developed seven distinct energy-efficient sets based on common building types found in remote, northern communities, including mechanical/construction garages, ice arenas, schools, meat packing facilities, grocery stores, medical centres, and office buildings. Each audit set provided energy-efficient improvements by building type, proposed changes to building operation to shift energy peak loads, equipment enhancements for improved efficiencies, and/or energy-efficiency modifications to the building envelope. Included within the recommendations were, where possible, descriptions of the benefits of each improvement, including the cost, payback period, and recommendations for suitable equipment models and vendors. This set of energy-efficient briefing materials was subsequently shared with municipal and business contacts throughout the Kitikmeot Region.

After initial discussions with building owners, and prior to installation of energy-monitoring equipment, POLAR sought the advice and guidance of the Government of Nunavut's Director of Safety Services and Chief Electrical Inspector as well as the Electrical Inspector for the Kitikmeot Region regarding compliance with the electrical code of Nunavut and safety inspection protocols that needed to be in place (pre-installation, installation, and post-installation) for the load-monitoring instrumentation. This advice informed CanmetENERGY's selection of the AccuEnergy AcuPanel 9100 series plug-and-play meters for this project.

Upon receiving ten AcuPanel meters in Cambridge Bay, POLAR initiated contract negotiations with local electrical

contractors for up to ten community-based installations. Based around CanmetENERGY's installation guidelines, and conducting a risk assessment for both installing and operating the meters, a sequential installation plan was developed. The first units selected for installation were the two schools, as these would benefit from frequent daily building checks by the building manager, and so ascertain early if there would be need for changes to the operation and installation methodology, which would affect future locations. Once a successful proof of concept has been completed at both schools, the next eight installations will be scheduled and conducted. From there, NRCan CanmetENERGY and POLAR will monitor installations and results over the course of the 2018–2019 winter.

Community considerations

Energy efficiency is one of the key reasons for diesel reduction, and greenhouse gas emissions will be cut significantly in remote communities. Identifying how energy can be better used and saved can lead to great economic benefits for individuals, communities, and utilities, as well as improved living conditions for occupants of residential units. By better understanding how energy is being used in remote communities (commercially, residentially, and on a municipal scale), it will be possible to identify where energy efficiency measures can be best targeted and propose changes to operating procedures to reduce peak loading. As part of this project, both NRCan and POLAR have committed to work with project participants in the community of Cambridge Bay to help identify how energy is being used in individual units and propose energy efficiency measures that can reduce costs. By better understanding energy usage on a community scale, it will also be possible to greatly reduce community diesel consumption for both heat and electricity generation. This will not only reduce overall costs to the community, but will ultimately lead to cleaner air and a healthier environment. This project will also help pave the way for future clean energy integration into the Cambridge Bay microgrid, thereby further reducing overall diesel dependency. This information will also, in part, be transferable to other remote communities, thereby allowing similar communities to benefit from energy efficiency improvements and diesel reduction opportunities identified by this project.

Conclusions and next steps

Although well underway, project progress was initially slower than anticipated, hampered by contracting and regulatory issues, both of which required considerable effort on the part of the POLAR engineer based in Cambridge Bay to help resolve. Initial installations have now been completed and monitoring work is underway. CanmetEnergy and POLAR are now moving forward with the next batch of installations with a view to having a minimum of ten high-energy-usage units under a monitoring protocol before the end of the 2018-2019 financial year. A lot of the work that has been done to date under the auspices of Phase 2 will greatly aid in the execution of Phase 3, the techno-economic assessment of the renewable energy microgrid design and operation with load management in Alaska and Nunavut, thereby allowing that phase to move forward more quickly than initially planned.

Combined, all three phases of this project have a great deal of potential to greatly reduce fossil-fuel usage by encouraging and aiding the uptake of appropriate renewable resources as a replacement for diesel and by identifying and shaping energy loads and efficiency, thereby reducing the overall need for energy generation.

Finally, this project has proved to be highly beneficial in establishing a collaborative working partnership between NRCan CanmetENERGY and POLAR, and is another step towards POLAR's goal of testing and demonstrating technologies at CHARS and in Cambridge Bay, thereby reducing the risk for future energy generation projects in Canada's remote Arctic communities.

Acknowledgements

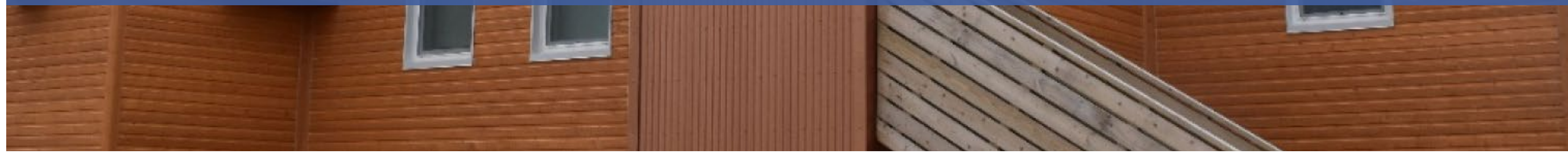
The following personnel were key to delivering the REMFTA project to date; Team lead Dr. Yves Poissant of NRCan CanmetENERGY, Jr. Engineer Alexandre Côté, and Microgrid Project Engineer Naveen Goswamy developed and submitted the project proposal to the NRCan ECO-EII. Richard Kelly, Director of Safety Services for the Government of Nunavut, and Richard Tourangeau, Electrical Inspector for the Kitikmeot Region, provided support and advice regarding electrical installations and regulations. Qulliq Energy Corporation provided

energy-usage data in order to determine which high-energy-usage units should be considered for monitoring. Jago Services Inc. of Cambridge Bay provided advice on installations and conducted all physical installations.

References

AccuEnergy. Pre-Wired Power and Energy Meter Panel: AcuPanel 9100 series. 2018. URL: https://www.accuenergy.com/product/acupanel-9100-pre-wired-panels

ACHIEVING BENEFITS THROUGH GREYWATER TREATMENT AND REUSE IN NORTHERN BUILDINGS AND COMMUNITIES



Nicole A. Poirier[1 *] **and Ramona Pristavita**[1]

[1] *Terragon Environmental Technologies Inc., Montréal, Québec, Canada*

* *nicole_a_poirier@outlook.com*

Terragon Environmental Technologies Inc. is an award-winning cleantech company founded in 2004 and based in Montréal, Québec. Terragon develops simple appliances for solid waste, wastewater, and sludges that enable any habitat to treat its own waste locally with no environmental damage and with significant benefits from the recovery of valuable resources.

Abstract

Greywater (GW) treatment and reuse is usually associated with regions facing water shortages. While some Arctic regions do lack sources of water, GW treatment and reuse may be of interest to most regions, since they typically have a high cost of truck-delivered potable water, low per capita consumption, and challenges with wastewater management. A suitably designed GW treatment system that takes into account northern constraints could provide significant benefits. Treated GW could be used for toilet flushing and other non-potable applications, thus reserving costly potable water for uses requiring this quality while also minimizing the volume of wastewater generated. In preparation for a GW treatment demonstration project in Cambridge Bay, Nunavut, a novel GW treatment system was evaluated over a six-month period. The system treated real shower and laundry GW, in some cases adjusted to more closely resemble GW expected to be found in the North. Treatment performance was compared with the NSF/ANSI 350 standard for residential and commercial buildings. It was found that the GW treatment system operated reliably and was able to meet the requirements of the NSF/ANSI 350 standard for all GW tested.

Introduction

Cambridge Bay is a hamlet located on Victoria Island in the Kitikmeot Region of Nunavut, Canada. In 2016, the population was 1,716, with the majority of residents being Aboriginal (Inuit) (Statistics Canada 2016). Because of permafrost and the harsh climate in Cambridge Bay, piped-water-distribution systems (underground or overground) and wastewater-collection systems are extremely costly and impractical. Thus, as in most Nunavut communities, homes and businesses in Cambridge Bay are equipped with separate water- and sewage-holding tanks for truck delivery of potable water and truck collection of wastewater. These truck services are provided for a fee by the hamlet, with different rates for residential and commercial customers. Potable water is generated from treated surface water and wastewater is disposed of in a nearby sewage lagoon.

The Cambridge Bay cost of water (economic rate) is $75/m^3 (including delivery and pump-out), although with government subsidies, the cost is reduced to $23/m^3 for commercial customers and $6/m^3 for non-commercial customers (Hamlet of Cambridge Bay By-Law 232). For

Suggested citation:

Poirier, N. A. and Pristavita, R. 2018. Achieving benefits through greywater treatment and reuse in northern buildings and communities. Polar Knowledge: Aqhaliat 2018, *Polar Knowledge Canada, p. 131–137. DOI: 10.35298/pkc.2018.16*

comparison, combined water and wastewater rates and fees in major Canadian cities are generally less than \$5/ m^3 for residential and commercial customers. Residential per capita water use in Nunavut is typically around 100 L/day, which is approximately one third of the Canadian average (Daley et al. 2014). Additionally, Nunavut's diesel-generated electricity cost is approximately 5 to 10 times higher than in other Canadian regions.

Treating greywater (GW) from bathing and laundry activities and storing it in a separate treated GW tank for use in applications that do not require potable water (e.g., toilet flushing and laundry) is an approach which could be considered to reduce costs and reserve clean water for those applications that truly require potable quality (i.e., drinking, cooking, and bathing). GW reuse can also decrease the per capita volume of potable water required and volume of sewage generated. GW reuse could ease the load on potable water treatment facilities and/or truck delivery services that may be operating near capacity in some communities. Commercial water users may be especially interested in GW reuse, given that they pay considerably more for their trucked services than residential customers.

GW treatment and reuse generates high interest in many regions of North America because of water shortages resulting from drought and/or a mismatch between water availability and domestic, agricultural, and industrial needs. However, GW treatment and reuse has rarely been considered for the North because of various challenges, including technical, practical, and social challenges. In this project, a novel GW treatment system will be evaluated and demonstrated to assess its suitability for treating GW generated in northern settings. Following this, the best options for deriving benefits from GW treatment and reuse in the North will be identified using techno-economic analyses and feedback from local community residents, gathered by Nunavut Arctic College students.

This paper contains the results of a six-month evaluation of the GW treatment system carried out in Montréal in preparation for the system installation in a triplex residence (Fig. 1) at the Canadian High Arctic Research Station (CHARS).

Challenges for greywater treatment in the North

Many GW treatment and reuse initiatives occur in warm climates where treatment equipment can be located outside. For the North, consideration has to be given to installing GW treatment systems inside buildings or heated enclosures. Many northern homes are small, sometimes overcrowded, and built on stilts (piles) because of permafrost; thus, residential single-family homes generally have no basements and no space available to accommodate GW treatment equipment. GW systems may be more easily and preferentially integrated into other types of buildings (i.e., multi-occupancy, commercial, governmental, educational) or at a central receiving site where GW from several separate sources is accepted and treated. Finally, some commercially available GW treatment approaches rely on treatment trains that are not compatible with northern operation, because of consumable requirements (e.g., chemicals) and maintenance requirements or the inability to treat northern GW to accepted GW-reuse standards.

Greywater treatment system set-up for evaluation

A novel automated GW treatment system not based on chemical addition or biological treatment was assessed over a six-month period. The system was operated Monday to Friday during the day only. The system had a capacity of 1.44 m^3/day, required about 0.5kW to operate, and is shown schematically in

Figure 1: Triplex residence at the Canadian High Arctic Research Station (CHARS), where the greywater system will be installed in November 2018.

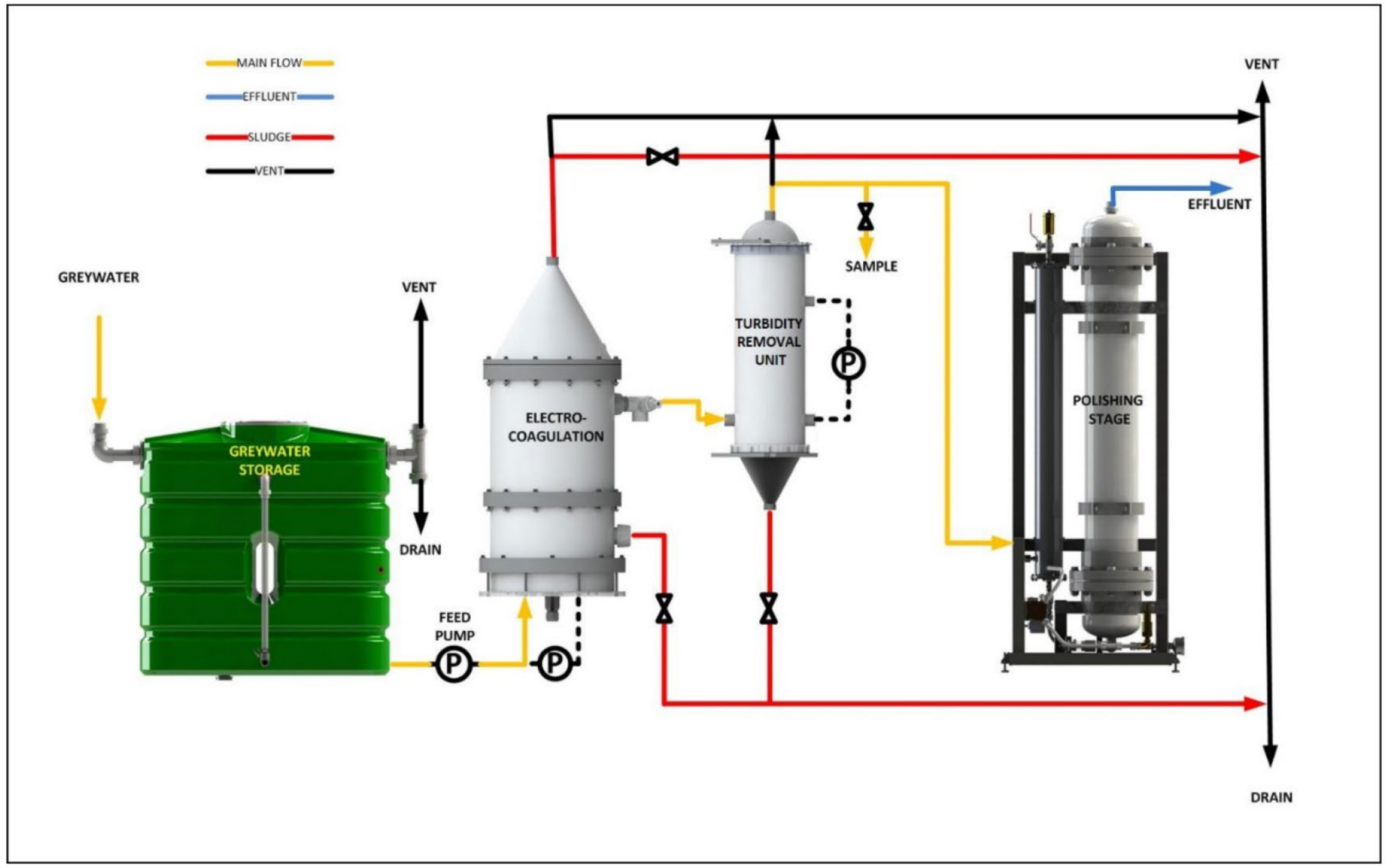


Figure 2: Schematic of the greywater treatment system.

Figure 2. It consisted of a GW receiving tank to collect GW (from showers and laundry), a patent-pending electrocoagulation unit serving to remove the majority of particulate contaminants and organic loading, a turbidity removal unit, and lastly, an adsorption column for final polishing. The treated GW was collected in a storage tank and disinfection was achieved using an in situ electrochemical process. During the evaluation, the electrocoagulation electrodes were replaced once, using a 10-minute procedure.

The GW treatment system was installed in the basement of a Montréal college sports complex (Fig. 3); the system to be installed at CHARS will be more compact and enclosed. GW that was treated came from the showers as well as from a domestic washing machine used to wash team uniforms and employee laundry. The treated GW was used as flush water for a nearby toilet — this aspect is important because a previous investigation indicated that over time, improperly treated GW can have negative impacts on toilet flush mechanisms and result in biofilm growth in the tank (Kuru and Luettgen 2012).

Greywater reuse standards

For decentralized greywater treatment, NSF International developed a 2011 standard (NSF/ANSI 350: *Onsite Residential and Commercial Water Reuse Treatment*), which describes the required criteria for water reuse systems. The standard has now been adopted by plumbing and building codes, and was used in this project to assess the performance of the novel GW treatment system. The treatment thresholds for residential (≤5,678 L/day) and commercial (> 5,678 L/day) applications are presented in Table 1.

Greywater characterization and composition

The mixed GW from showers and laundry, as well as GW from showers alone and laundry alone, were sampled over a two-week period and fully characterized. The results are presented in Table 2, where it can be seen that the strength of the GW from laundry alone is an order of magnitude higher than that of GW from

POLAR KNOWLEDGE Aqhaliat

Figure 3: Greywater treatment system set-up used during the evaluation in Montréal.

showers alone. Following this initial GW characterization period, selected GW parameters were measured each week throughout the six-month trial; typically these included, at a minimum, the chemical oxygen demand (COD), biochemical oxygen demand (BOD5), and total suspended solids (TSS).

The GW generated during the six-month trial was derived from activities making use of the potable water available in Montréal. However, potable water available in Cambridge Bay (and many other northern regions) can have somewhat different characteristics, often containing a greater amount of natural organic material (NOM) derived from the breakdown of plant and animal material. The main component of NOM is humic acid; humic substances typically account for 40%–80% of the dissolved organic matter in water, with lesser contributions from fulvic acid (Uyguner 2007).

During a visit to Cambridge Bay in late July 2017, tap water at the CHARS triplex was found to have a COD of 8–22 mg/L, as determined by a Mantech PeCOD analyzer (0.7 mg/L detection limit); source water used to create the potable water was also found to have similar COD values, assumed to be due primarily to NOM. Northern water may also contain disinfection by-products, minerals, and heavy metals, depending on the surface water source and the potable water treatment process used.

To investigate the potential impact of NOM on GW treatment, GW produced by the Montréal college was spiked with known quantities of humic acid (Plant Products Ez-Gro 80% Humic Acid). As well, Montréal

Table 1: NSF/ANSI 350 greywater treatment requirements for residential (Class R) and commercial (Class C) reuse.

		Class R		Class C	
Parameter	**Units**	**Overall test average**	**Single sample maximum**	**Overall test average**	**Single sample maximum**
CBOD5	(mg/L)	10	25	10	25
TSS	(mg/L)	10	30	10	30
Turbidity	(NTU)	5	10	2	5
E.coli[2]	(MPN/100 mL)	14	240	2.2	200
pH	(SU)	6 - 9	NA[1]	6 - 9	NA
Storage vessel disinfection	(mg/L)[3]	≥0.5 - ≤2.5	NA	≥0.5 - ≤2.5	NA
Color		MR[4]	NA	MR	NA
Odor		Non-offensive	NA	Non-offensive	NA
Oily film and foam		Non-detectable	Non-detectable	Non-detectable	Non-detectable
Energy consumption		MR	NA	MR	NA

[1]NA = Not applicable

[2]Calculated as geometric mean

[3]As chlorine. Other disinfectants can be used.

[4]MR = Measured and reported only

Table 2: Characterization of greywater from shower water (SW) and laundry water (LW).

		3-Sep-17	21-Sep-17	26-Sep-17	28-Sep-17	10-Oct-17
Parameter	**Units**	**Sample 1 (SW)**	**Sample 2 (SW+LW)**	**Sample 3 (SW+LW)**	**Sample 4 (SW+LW)**	**Sample 5 (LW)**
COD	(mg/L)	122	208	133	218	1840
BOD_5	(mg/L)	70	120	87,5	117,5	655
TSS	(mg/L)	19	36	23	15	340
PT	(mg/L PO_4^{3-})	4,5	2,6	3,64	5,25	-
pH	-	7,69	7,94	7,84	8,46	7.51
Conductivity	(µs/cm)	512	496	465	554	621
Turbidity	NTU	13,2	38,7	20,9	15,3	483
Alkalinity	(mg/L $CaCO_3$)	162	150	132	185	-
N-NH_3	(mg/L)	16,4	11,3	10,25	18	-
TOC	(mg/L)	26,3	44,1	21,9	53,8	-
TKN	(mg/L)	-	15,1	-	26,7	42.4
Oil & Grease	(mg/L)	-	20	-	15	252
Fecal Coliform	(UFC/100 mL)	-	72	-	-	170 000
Total Coliform	(CFU/100 mL)	-	800 000	-	-	800 000
E.coli	(CFU/100 mL)	-	60	-	-	5000

potable water not contaminated by any GW was spiked with high concentrations of humic acid and then treated with the GW treatment process.

Greywater treatment results

After several trial periods during which the electrocoagulation unit was operated at different current intensities, an optimal current intensity was selected and used for the remainder of the trial (November 2017 to mid-February 2018). Figures 4 and 5 present the GW influent and GW effluent values for COD, BOD5, TSS, and turbidity. The NSF/ANSI 350 treatment standards presented in Table 2 were met, and pH (not shown) remained within the range of 6–9, as required.

The influence of NOM on the GW treatment was investigated by adding humic acid to the GW present in the collection tank, with the goal of achieving an NOM concentration of approximately 30 mg/L. Once added to the GW collection tank, it was unfortunately not possible to effect any mixing of the NOM concentrate with the GW. The COD of the GW being sent to the treatment system after the NOM addition attained a maximal value of 1,235 mg/L, and over a period of one hour gradually decreased to 584 mg/L (still considerably higher than the typical GW influent COD value). Despite this high GW influent COD, the GW treatment was still successful in meeting the NSF/ANSI 350 standards. Another trial was next carried out to see if the GW treatment process could be used to treat a highly concentrated solution of humic acid (150 ppm of Plant Products Ez-Gro 80% Humic Acid) in potable water not contaminated by any GW. Figure 6 shows that the treatment process was still highly effective, and thus it can be concluded that northern GW can be treated to NSF/ANSI 350 standards even if such GW is generated from potable water containing a background concentration of NOM.

Regarding disinfection, microbiological parameters were measured periodically, and the values obtained are presented in Table 3. The electrochemical approach used to generate oxidants in situ in the GW effluent holding tank was successful in creating a small chlorine residual between 0.5 and 2.5 mg/L and in reducing the E. coli to 14 CFU/100 mL, as required by NSF/ANSI 350. No biofilm was observed in the toilet tank over the six-month period and no issues were encountered with the flushing mechanism.

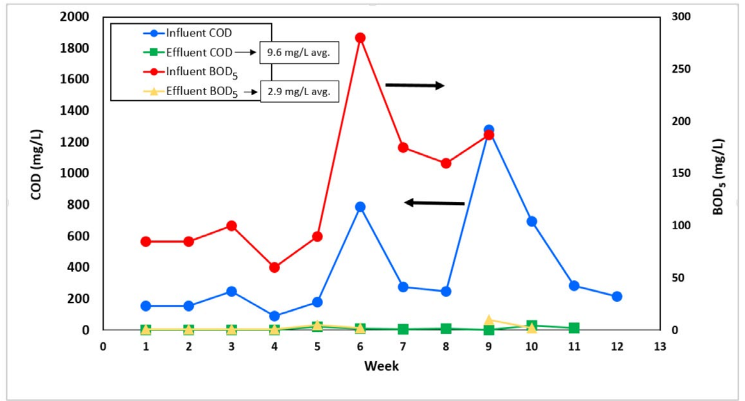


Figure 4: Greywater influent and greywater effluent COD and BOD5.

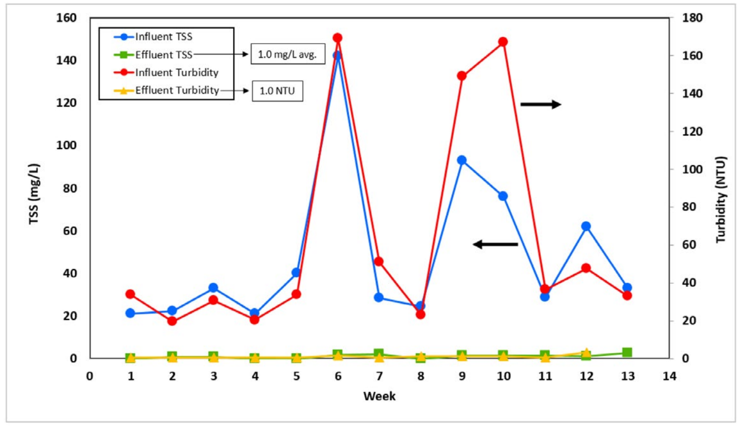


Figure 5: Greywater influent and greywater effluent TSS and turbidity.

Community considerations

Beyond techno-economic aspects, an important consideration for the success of a GW treatment initiative, not only in the North but anywhere, is the receptivity of the concept by community residents. The deeply rooted Inuit cultural and social perceptions regarding water will be investigated through a series of surveys and exchanges with local residents, carried out by Nunavut Arctic College students.

Conclusions

The novel greywater treatment technology was able to reliably treat real greywater generated from showering and laundry activities at a Montréal college over a period of six months. The treated GW characteristics respected

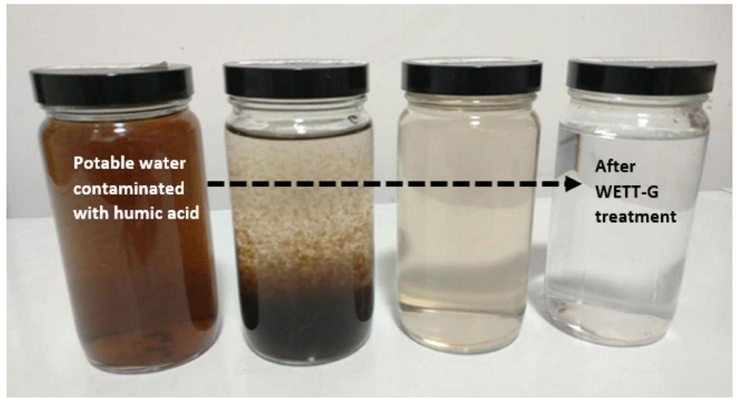


Figure 6: Montréal potable water spiked with humic acid and treated with the greywater treatment system.

the requirements set forth by the NSF/ANSI 350 standard for greywater treatment. Even when greywater or potable water was doped with high concentrations of NOM, in the form of humic acid such as may be found in northern GW, these same results were achieved.

Acknowledgements

We gratefully acknowledge the contribution of Dr. Rimeh Daghrir of Cégep de Saint-Laurent to this project and the financial support for this project from Polar Knowledge Canada and the Natural Sciences and Engineering Research Council of Canada.

References

Daley K., Castleden, H., Jamieson, R., Furgal, C., and Ell, N. 2014. Municipal water quantities and health in Nunavut households: An exploratory case study in Coral Harbour, Nunavut, Canada. *International Journal of Circumpolar Health* 73:23843. doi:10.3402/ijch.v73.23843. Available from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3970036/ [accessed 29 March 2018].

Hamlet of Cambridge Bay, NU. By-law No. 232–Schedule A: Water and sewer rates for municipal services. 24 pp. Available from http://www.cambridgebay.ca/sites/default/files/By-Law%20232%20-%20Water%20Sewer.pdf [accessed 29 March 2018].

Table 3: Greywater disinfection results.

Sample	Microbiological Analysis	Units	Untreated Greywater	Untreated Greywater	After Disinfection	Free Chlorine (mg/L)	Initial pH	Final pH
15-11-2017	Fecal Coliform	(CFU/100 mL)	2900	<10	<10	-	7.81	7.4
	Total Coliform		CTN[1]	<10	<10			
	E. Coli		2400	200	81			
21-11a-2017	Fecal Coliform	(CFU/100 mL)	30 000	<10	<10	-	7.03	7.66
	Total Coliform		>800 000	36000	<10			
	E. Coli		500	<10	<10			
28-11-2017	Fecal Coliform	(CFU/100 mL)	210	<10	<10	1.34	7.37	7.6
	Total Coliform		>800 000	7900	<10			
	E. Coli		99	<10	<10			
5-12-2017	Fecal Coliform	(CFU/100 mL)	1400	<10	<10	1.2	7.69	7.99
	Total Coliform		>800 000	550	<10			
	E. Coli		2400	<10	<10			
12-12-2017	Fecal Coliform	(CFU/100 mL)	<10	<10	<10	0.11	6.69	7.55
	Total Coliform		>800 000	11000	310			
	E. Coli		98	<10	<10			
13-02-2018	Fecal Coliform	(CFU/100 mL)	-	-	-	0.18	7.96	7.83
	Total Coliform		>600 000	-	<10			
	E. Coli		990	-	<10			

[1]CTN = Colonies too numerous to measure

Kuru, B. and Luettgen, M. 2012. Is gray-water reuse ready for prime time? Available from https://www.us.kohler.com/webassets/kpna/pressreleases/2012/KOHLER-GRAYWATER_111412.pdf [accessed 30 March 2018].

Statistics Canada. Census profile, 2016 census, Cambridge Bay [population centre], Nunavut and Nunavut [Territory]. Available from http://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/details/page.

Uyguner, C.S., Bekbolet, M., and Swiétlik, J. 2007. Natural organic matter: Definitions and characterization. In Advances in control of disinfection by-products. Nikolau, A., Selcuk, H., and Rizzo, L. (eds.), Nova Science Publishers Inc., New York. pp. 419–446. Available from https://www.researchgate.net/profile/Ceyda_Uyguner_Demirel/publication/286329976_Natural_organic_matter_Definitions_and_characterization/links/566ebcba08aea0892c52a5df/Natural-organic-matter-Definitions-and-characterization.pdf [accessed 25 April 2018].