Annual reporting for GNWT Environmental Studies Research Fund – 2020/21

Title: Assessing terrain sensitivity to permafrost thaw and fire to understand and predict boreal caribou habitat and forage quality in the Sahtú

Investigators: Drs. Jennifer Baltzer (jbaltzer@wlu.ca) and Merritt Turetsky (merritt.turetsky@colorado.edu)

Collaborators: Drs. Steve Kokelj, Sharon Smith, Andrew Spring, Dave Rudolph, and Derek Gray

Project Description: The proposed research will address how fire and permafrost conditions interact to determine caribou habitat responses to climate change and human activity in the Sahtú, a resource-rich region poised for substantial oil and gas development. Using a combination of field measurements and remotely sensed land cover change, we will improve predictions about the sensitivity of permafrost to fire and human activity in the Sahtú and how this relates to caribou forage availability and quality and caribou habitat use. This will be accomplished by quantifying key metrics of land cover change, terrain stability, and vegetation across a range of permafrost conditions and disturbance gradients.

Progress during 2020/21 Funding Year

Research team: We have an excellent team of researchers to support this work as outlined in Table 1 below. For 2018 field work we directly collaborated with HQP from the research groups of Drs. Rudolph and Gray to promote integration of hydrologic (Rudolph), aquatic ecosystem (Gray) and terrestrial measurements (Baltzer/Turetsky) measurements in the region.

Name	Position	Funding
Carolyn Gibson	PhD student	University of Guelph
Kirsten Bill	MSc student	ESRF
Ana Sniderhan	Research Associate	Global Water Futures
Emily Ogden	MSc Student	NSERC SPG
Alexis Jorgensen	MSc Student	ESRF
Jessica McCuaig	MSc Student	NSERC SPG
Jason Paul	Research Technician	Wilfrid Laurier University
Maria Belke-Brea	Postdoc	Polar Knowledge Canada
Ceres Barro	Postdoc	CIMP and Global Water Futures

2) Community consultation

Thermokarst and wildfire were both identified as key community concerns at the Sahtú Environmental Monitoring Research Forum meeting in Tulita that our team attended in February 2018. Although fieldwork was not possible during 2020 nor were any in person knowledge sharing activities, we have had several Zoom meetings with the Sahtú Renewable Resources Board to share information on the project progress and discuss plans for the coming summer.

To enhance our capacity for community consultation and engagement, in collaboration with the Sahtú Renewable Resources Board, Leon Andrew and Jennifer Baltzer are co-leading a Global Water Futures project to support on the land camps that will lead to improve knowledge sharing between researchers and community members. The first of these camps took place on Tek'áícho Dǝ́ (Marten River*)* in August 2019 and involved members of our ESRF team (Ogden, Gibson, and collaborator Grey). We are in the planning stages for the second camp, delayed due to COVID, but which will take place in Fort Good Hope in August 2021.

Figure 1*. On-the-land cross cultural camp on Tek'áícho Də́ (Marten River) held as a collaboration between the community of Tulita, the Sahtu Renewable Resources Board and the Global Water Futures Water Knowledge Camps program.*

Research progress
Below, we provide updates on three distinct though interconnected components of this project:
1) Thermokarst vulnerability assessments
2) Vulnerability of lichen peatlands to fire and thaw
3) Post-fire forage lichen forage recovery

Thermokarst vulnerability assessments
We are employing the framework presented in our 2017/18 and 2018/19 reports to evaluate thermokarst vulnerability in the Sahtú region.

Figure 2*. Permafrost coring and peat sampling in a collapse scar in the Sahtú region. Photos courtesy of Emily Ogden.*

Over the last year, we have made considerable progress toward this goal. The first steps of this framework involve the detection of thermokarst (Fig. 3). Gibson has completed the mapping of lowland thermokarst vulnerability for the entire Taiga Plains, including the Sahtú region as part of the NWT Thermokarst Collective initiative led by Dr. Steve Kokelj. This framework for this was described in the 2019/20 annual report and can be found in Gibson et al. 2020 and Gibson et al. 2021 (citations below).

Gibson, C, Cottenie, K, Gingras-Hill, T, Kokelj, SV, Baltzer, J, Chasmer, L, Turetsky, M. 2021. Mapping and understanding the vulnerability of northern peatlands to permafrost thaw at sclaes relevant to community adaptation planning. Environmental Research Letters, in press, https://doi.org/10.1088/1748-9326/abe74b.

Open Data Report: Gibson, C., Morse, P.D., Kelly, J.M., Turetsky, M.R., Baltzer, J.L., Gingras-Hill, T., and Kokelj, S.V., 2020. Thermokarst Mapping Collective: Protocol for organic permafrost terrain and preliminary inventory from the Taiga Plains test area, Northwest Territories; Northwest Territories Geological Survey, NWT Open Report 2020-010, 24 pages, appendix, and digital data. https://tinyurl.com/nwfreport2020

Using these gridded data, Gibson et al. 2020, 2021 also greatly improved on predictions of lowland thermokarst vulnerability from for the entire Taiga Plains, including the areas around Tulita and Norman Wells compared to previous global scale products of thermokarst vulnerability. The comparison of these two data products and their differences is presented in Fig. 3.

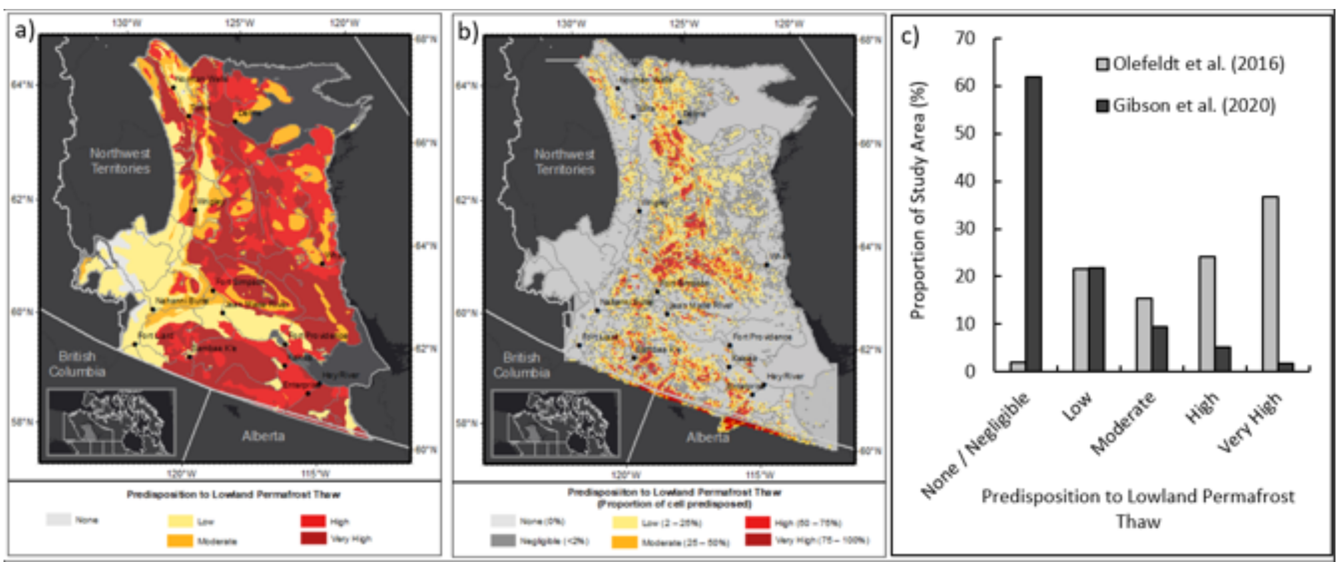

***Figure 3**. Comparison of geospatial products of lowland thermokarst probability in permafrost peatlands in the discontinuous permafrost zone of the Taiga Plains Ecozone within the Northwest Territories, Canada. (A) The Olefeldt et al. (2016) framework was developed for use at circumpolar scales. (B) Results from this study uses a gridded approach and was developed for use at regional or community-relevant scales. (C) Comparison of these two approaches binned by predisposition classes. Note that a negligible class does not exist within the Olefeldt et al. (2016) framework; thus, we combined none and negligible classes in this analysis. This figure is taken from Gibson et al. 2021.*

Vulnerability of lichen and peatlands to fire and thaw in the Sahtú
As described in the 2019/20 reporting, in 2019, we established new field sampling in lowland permafrost environments in the Sahtú region. Images and descriptions below are from the 2019 field campaign. These efforts were focused on permafrost peatlands dominated by caribou lichen cover (Fig. 4). Our

sample design involved characterizing vegetation communities and soil carbon stocks for peatlands ranging in fire-free interval (from sites that burned in 2014 to those that have not burned since 1969). Within each location, we sampled thermokarst bogs (Fig. 5) that were stable and those showing evidence of rapid permafrost thaw, permafrost plateau locations, and surrounding forest environments (Fig. 4). These sample efforts included:

1) measurement of soil organic layer thickness and carbon content and collection of permafrost cores for characterization of ground ice and permafrost carbon (Fig. 1, 6)
2) Measurement of carbon stocks in thaw features (Fig. 7).
3) Stand structure and composition (where relevant) and ground vegetation characterization (Fig. 1, 8) in all sampled features

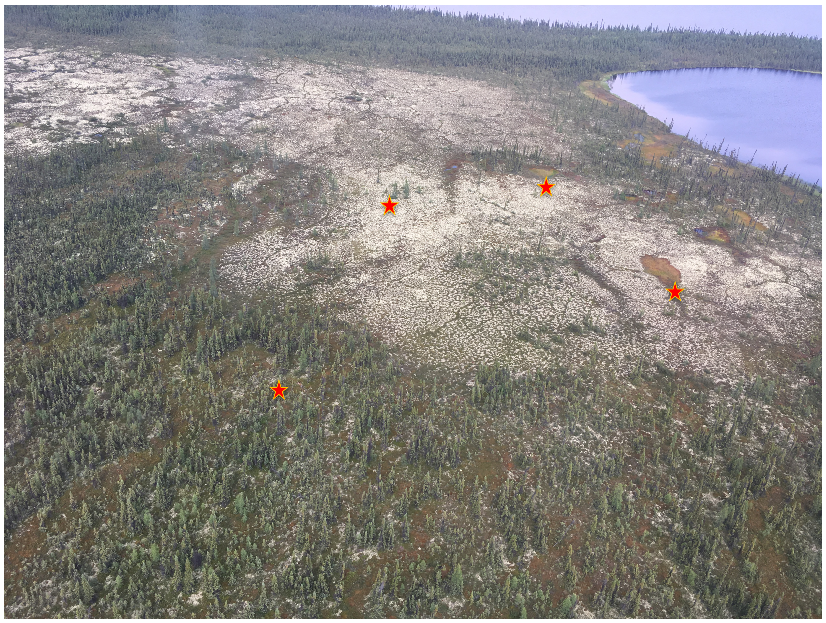

Figure 4. *Sampling locations within each lichen peatland including stable and unstable thermokarst bogs, permafrost plateau, and forest interior. This sampling included sites that burned in 2014, 2007, 1993, 1969, and "unburned controls" for which we will assess burn date based on stand age.*

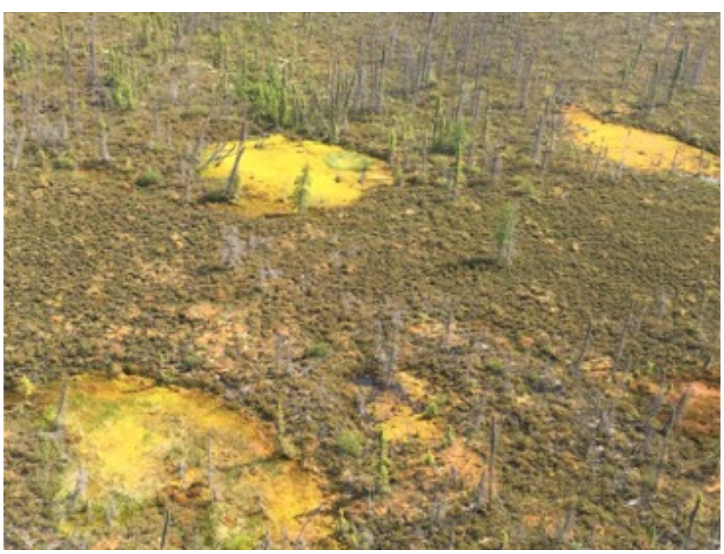

Figure 5. *Thermokarst bogs in a recently burned lichen permafrost peatland. Brighter green areas indicate regions of active thaw.*

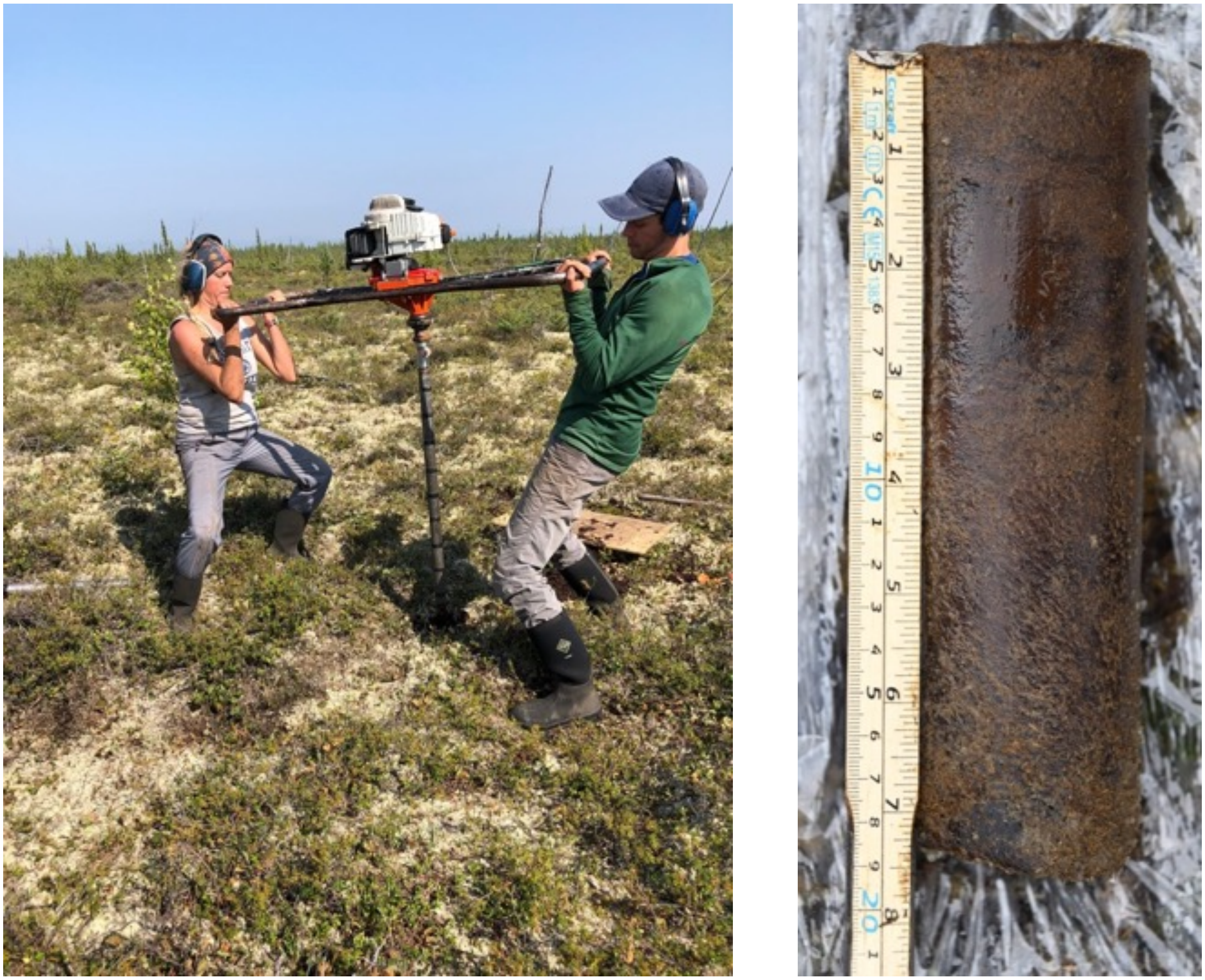

Figure 6. McCuaig and Paul coring permafrost in a lichen peatland (left) and peat-rich permafrost core segment (right).

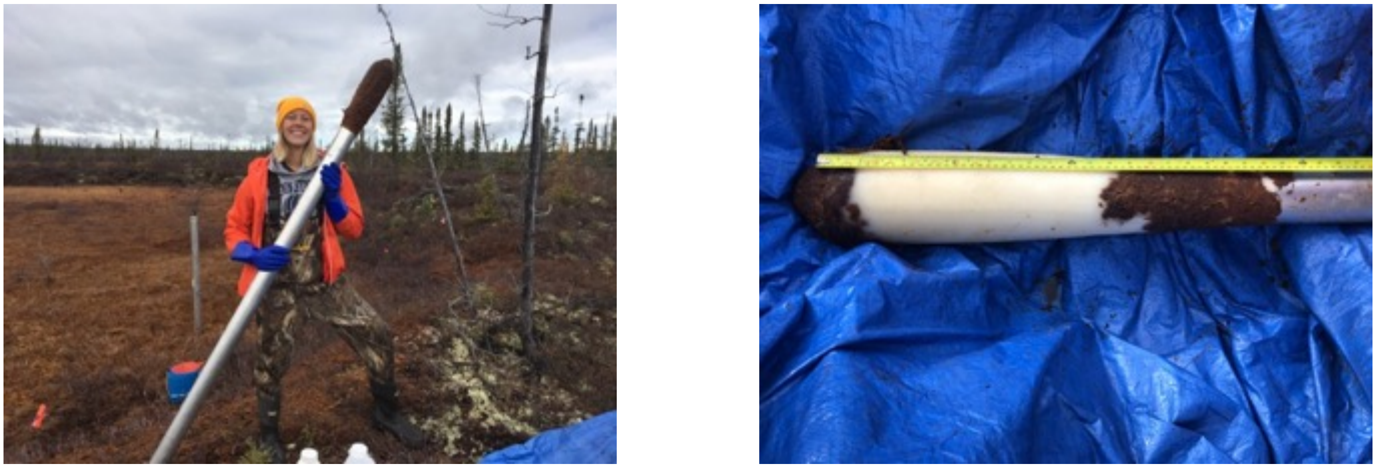

Figure 7. Frozen finger sampling in thermokarst bog features. McCuaig with frozen finger sampler (right) and a sample with water (frozen due to the sampling technique) between peat layers demonstrating the structure of these peatlands.

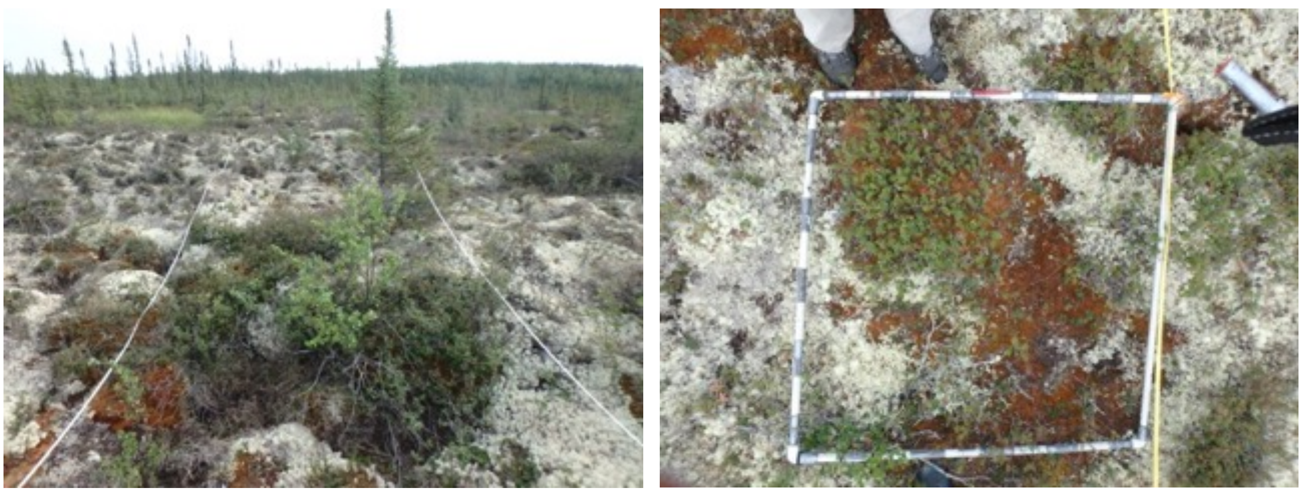

Figure 8. Vegetation sampling transect (left) and quadrat (right) in a lichen permafrost peatland.

Although fieldwork in 2020 was not possible, we have made good progress on quantifying the carbon stock recovery following fire in these peatlands. As part of this, the following analyses have been undertaken:

- 800 soil samples from permafrost plateaus spanning the entire soil organic layer have been processed for bulk density and loss on ignition (LOI). LOI provides us with an organic matter content measurement for each sample.
- 60 of the 800 samples have been sent for elemental analysis to determine carbon content to build a relationship with LOI and C content. N content information from the elemental analyzer will also be used to explore differences in N content between soil horizons. Analysis of the remaining samples has been delayed due to COVID, but preliminary results are presented below.
- We have built key relationships with estimated C content and time-since-fire. It appears these permafrost plateau sites are not recovering following fire and are continuing to lose carbon for 100 years post-fire (Figure 9). These preliminary results, though surprising, are in keeping with analyses

from the southern NWT (Bill et al, in prep) and Alaska (Mack et al. 2021. Science 372: 280-283) and draw into question the resilience of these peat-rich environments to disturbance.

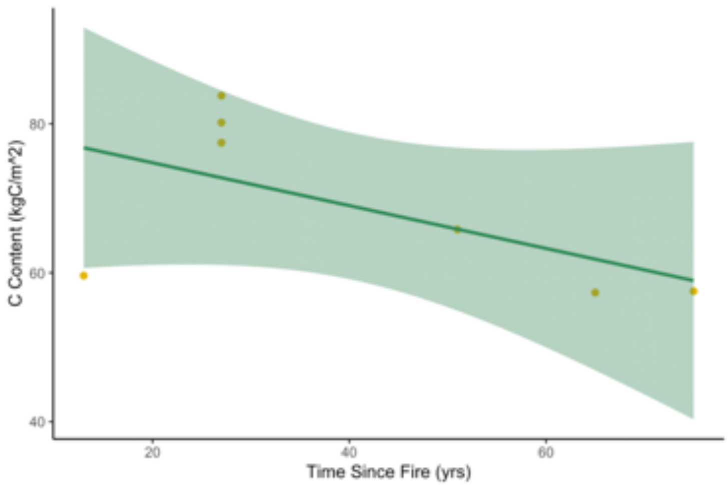

Figure 9. *Carbon content of permafrost plateaus decreases for 100 years following fire.*

When taking a closer look at where the carbon losses are specifically coming from, it appears that the fibric soil horizon continues to lose carbon for 100 years following while other horizons do not recover but also do not experience further loss (Figure 10).

- Although there is no relationship with bulk density and time-since-fire that would suggest increased decomposition of the fibric layer.
- It also appears that the active layer is deepening for 100 years following fire. This could be related to the C losses from the fibric layer as this would generally be the layer below the active layer.

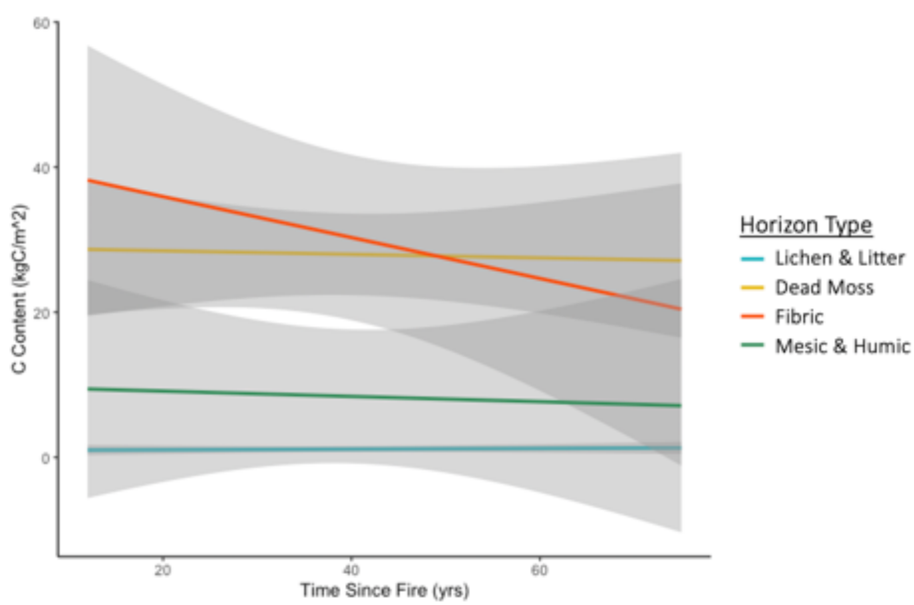

Figure 10. *Fibric layer continues to lose C for 100 years following fire while other soil horizons remain unrecovered.*

Basal peat layers have been identified using LOI, bulk density, and horizon type data. They will be processed using bulk peat sampling processes to be sent for radiocarbon dating. This will give us information on peatland initiation dates to ensure all sites are comparable. An incubation experiment will be conducted to understand the difference between soil horizons C stock stability following fire.

Post-fire forage lichen recovery

In 2018, we established 12 sites in which we sampled stand age, ground vegetation, soils development and forage lichen biomass recovery (points in the Sahtú region in Figure 11). We used methods identical to an ongoing study in the southern NWT, allowing us to compare these processes in the Sahtú, Tlicho and Dehcho regions. Further, for the lichen biomass sampling, a collaborator had comparable data from northern Saskatchewan facilitating a regional comparison of lichen biomass accumulation rates in northwestern Canada. This combined dataset has supported the first comprehensive evaluation of forage lichen recovery times following fire for the NWT and provides Sahtú-specific estimates as well. The resulting manuscript was developed by Degré-Timmons and is currently in :

Gruel, RJ, Degrè-Timmons, GE, Baltzer, JL, Johnstone, JF, McIntire, EJB, Day, NJ, Hart, SJ, McLoughlin, PD, Schmiegelow, FKA, Turetsky, MR, Truchon-Savard, A, van Telgen, MD, Cumming, SG. 2021. Predicting patterns of terrestrial lichen biomass recovery following boreal wildfires. Ecosphere, 12: e03481
https://esajournals.onlinelibrary.wiley.com/doi/epdf/10.1002/ecs2.3481

Associated open Dataset: Baltzer, J, Degré-Timmons, G, Day, N, Cumming, S, Turetsky, M, Johnstone, J. 2021. Terrestrial lichen data for Northwest Territories, Canada, Dryad Dataset, https://doi.org/10.5061/dryad.t1g1jwt15

We are currently in the process of developing ecological forecasting tools to provide managers the ability to evaluate changes in forage lichens under different wildfire scenarios. In the coming summer, we will also be working to scale our ground plot data with NASA ABoVE high-resolution hyperspectral data (AVIRIS). Our current work on the interaction between fire and permafrost thaw will allow that to be extended to include scenarios of fire and thaw. Some of the key results from the paper are included in Figs 11 & 12.

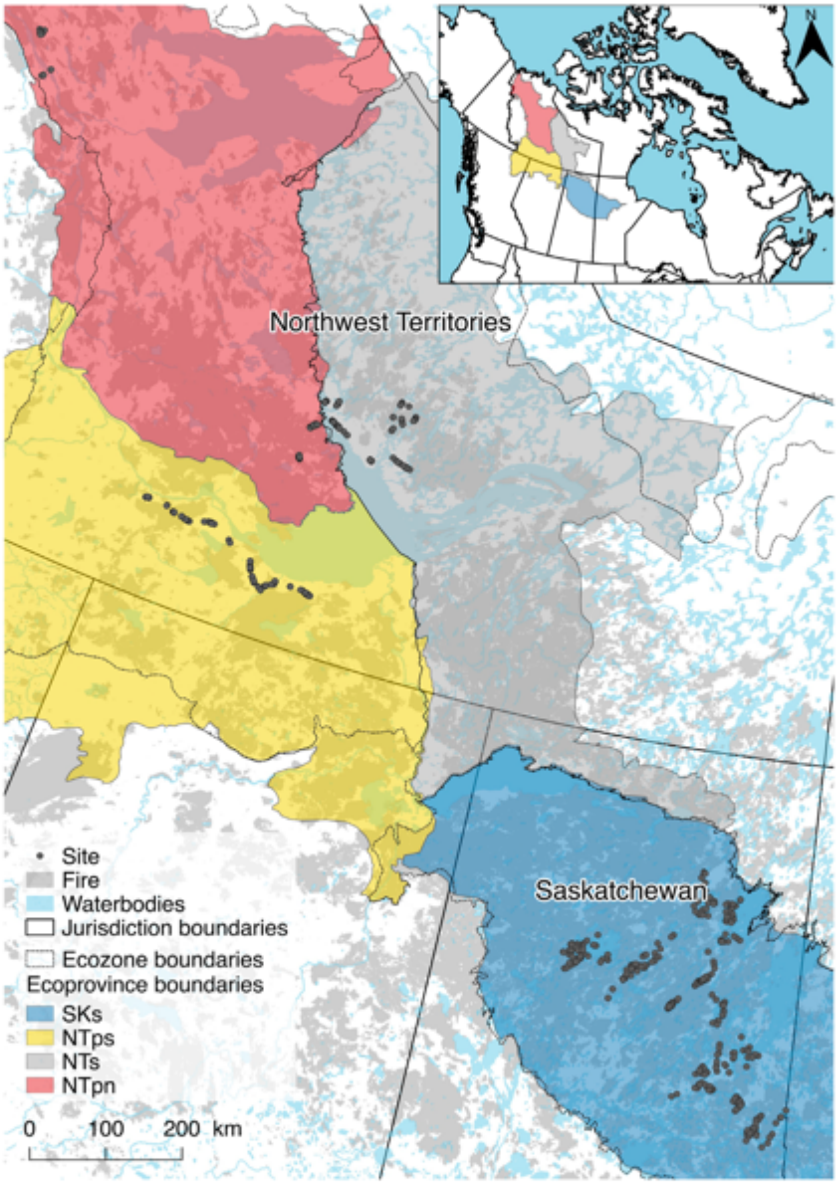

Figure 11. *Locations of all sampling locations used to evaluate post-fire recovery of lichen and its generalizability across northwestern Canada. Included in this broader analysis are our sampling efforts to date in the Sahtú region. From Gruel, Degre-Timmons et al. 2021.*

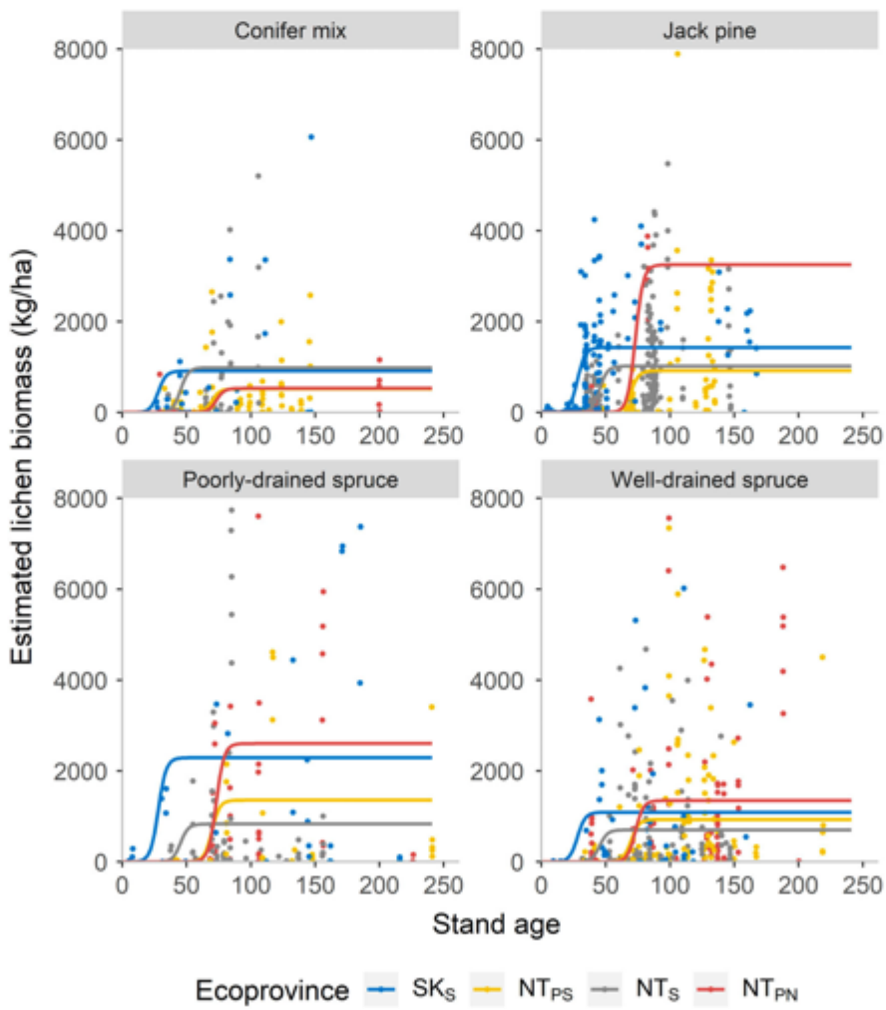

Figure 12. *Lichen biomass accumulation through time (stand age in years) in each ecoprovince for each stand type. Ecoprovince: SK_S = Saskatchewan Shield, NT_{PS} = Northwest Territories Plains South, NT_S = Northwest Territories Shield, NT_{PN} = Northwest Territories Plains North. We see the importance of poorly drained spruce in supporting high maximum lichen biomass accumulation across all regions. From Gruel, Degre-Timmons et al. 2021.*

Next steps:

Unfortunately, the COVID-19 situation prevented our 2020 field season requiring a one-year extension on the project. During 2020/21, Emily Ogden has been working with existing data on ground ice and ground thermal changes (collaborator S. Smith, GSC) to link remotely sensed measured of ecosystem productivity (NDVI) with changes in permafrost conditions. We are using this analysis to select sampling locations for the coming summer, during which we will have a team visiting these sites to collect a range of ecological data from lichen biomass and ground vegetation to tree growth to soil and permafrost carbon stocks. Site selection will use existing data on ground ice conditions (high, medium, low), rates of active layer thickening (documented using Dr. Smith's existing network of ground thermal monitoring stations), and remotely sensed changes in vegetation productivity (Ogden's MSc thesis work, which has used Landsat imagery to quantify) (Fig. 13). This will allow us to assess how changes in permafrost conditions over the last 20-40 years have affected land cover, associated caribou forage availability, and ecosystem productivity. We will also be sampling proximal waterbodies to attempt to link permafrost thaw rates to water quality in adjacent water bodies and will collaborate with Dr. Rudolph to evaluate the potential to draw further links with ground water inputs.

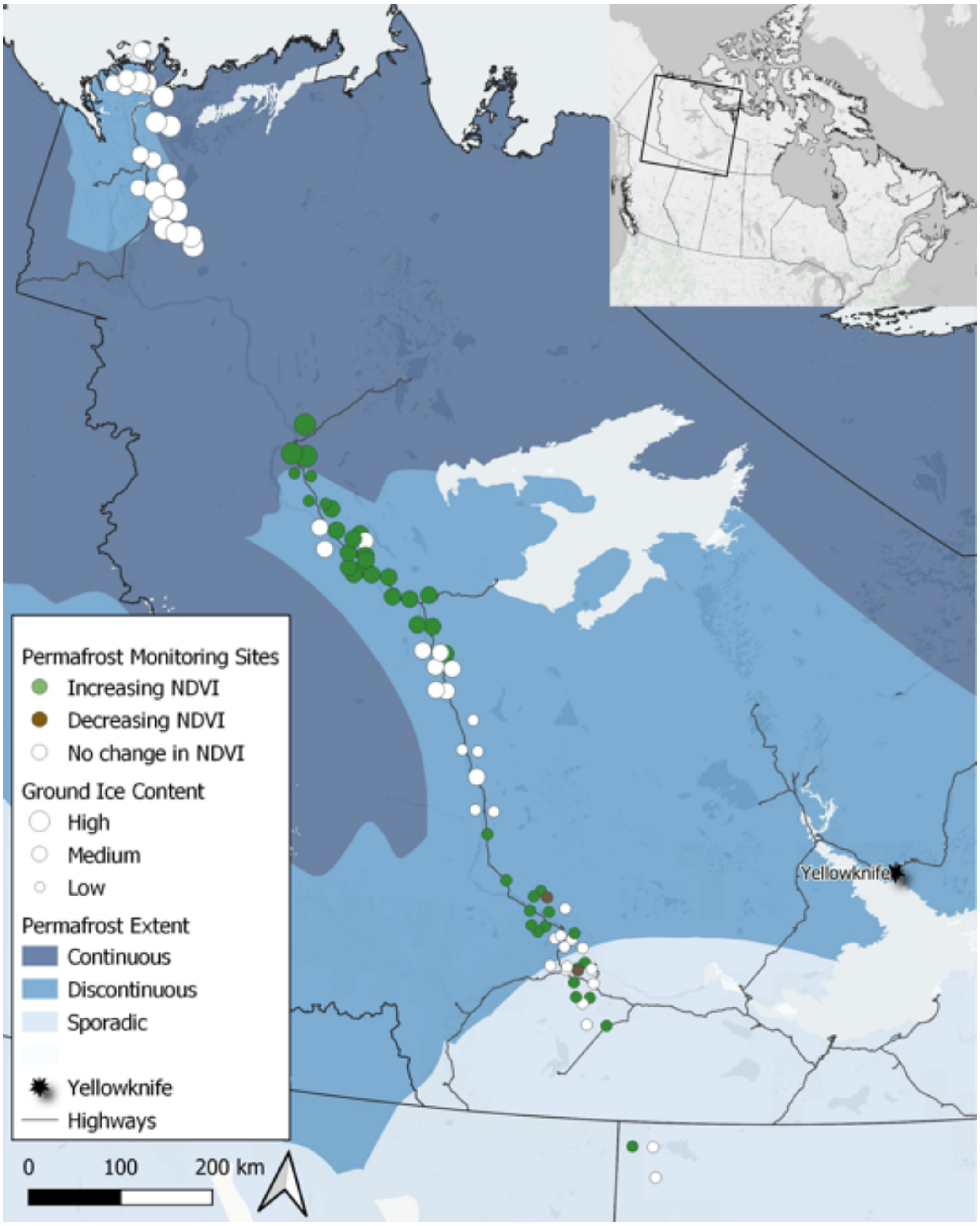

Figure 13. *Map of Geologic Survey of Canada ground thermal monitoring stations along the proposed pipeline corridor. Each of these sites includes data on ground ice (high, medium, low; depicted by the size of the symbols on this map), soil properties (from boreholes), and vertical profiles of ground temperature that have been measured at each site for between 20 and 40 years (depending on site establishment date). Normalized Difference Vegetation Index or NDVI, which provides a measure of the site productivity has also been characterized for these sites for the same time period based on Landsat time series. The direction of NDVI changes are indicated by the color of the symbols. Map courtesy of E. Ogden.*

Annual reporting for GNWT Environmental Studies Research Fund – 2020/21

Our planned on the land activities involving the community of Fort Good Hope were also postponed for a year but Kristen Bill (current PhD) has continued to engage this community to enhance our planning for that event which is scheduled for August of the coming summer. We have now had two planning meetings with Fort Good Hope leadership and Indigenous Guardian trainees.

Thermokarst vulnerability mapping and modelling efforts will continue through this and partner projects including Northern Water Futures and a recently funded NSERC Strategic Project Grant (see additional funding sources) and as part of our collaboration with the NWT Thermokarst Collective.

Progress toward proposed project deliverables
As evidence, we are making substantial progress toward the stated project deliverables:
1) Yrs 1-4: Collaborative community workshops in Tulít'a to identify areas important for caribou on the landscape
- Completed for 2017/18, 2019, postponed for 2020 due to COVID-19.
2) Yr 1: Research team involvement in the Sahtú Environmental Monitoring Research Forum meeting to engage the community further in the proposed research
- Completed; it is noteworthy that our extended project also supported a Forum call in 2019.
3) Yr 1: Review and synthesis of literature, data, and images on permafrost, fire, and caribou habitat in the Sahtú
- In progress – This forms part of MSc Alexis Jorgensen's thesis project and is currently being drafted.
4) Yr 1-3: Field surveys and analysis of data to establish relationships between fire, permafrost, and vegetation
- Successful field seasons in 2018 and 2019. 2020 field campaign delayed to 2021 due to COVID-19. We are actively preparing for a 2021 field season that will facilitate linkages between permafrost thaw and caribou forage availability.
5) Yr 2-3: Point based photointerpretation of change characteristics
- completed – PhD Carolyn Gibson's work cited above
6) Yr 3-4: Develop maps and related decision-aids for predicting and detecting areas with a high potential for thermokarst and land subsidence post-thaw
- In progress. PhD Carolyn Gibson's work has mapped the vulnerabilities and we have a postdoctoral fellow lined up to turn these maps into decision support tools using the SpaDES framework (www.predictiveecology.ca) in collaboration with Eliot McIntire, NRCan
7) Yr 3-4: Produce spatially explicit information on post-thaw landscape change and subsidence in critical caribou habitat
- In progress. 2019 and 2021 fieldwork will produce the data to finalize this goal. Ceres Barro has been hired to undertake the ecological forecasting tool development.

Leveraged funding to date
ESRF funds are being heavily leveraged against other funding sources as outlined below making the proposed research feasible.

1) Global Water Futures (~$20,000/year)
   - The salary of Dr. Ana Sniderhan is being supported by core funding to Wilfrid Laurier University from Global Water Futures. Dr. Sniderhan will lead the vegetation sampling in the Sahtú over the course of this project. During 2018, I anticipate that Ana will spend ~25% of her time on this project.
   - Travel support for Sniderhan

Annual reporting for GNWT Environmental Studies Research Fund – 2020/21

2) Northern Water Futures (~$50,000 per year)
    - The salary of Dr. Anna Coles was supported through Northern Water Futures until November 2018 at which point Anna took a position with the GNWT. Anna was dedicating roughly 50% of her time to this project.
    - Support for community outreach and engagement is available (during 2017, $10,000 was provided to support the Nę K'ə Dene Ts'ıį̨ ı̨ Forum workshop; during 2019, a similar amount will help to support the on-the-land camps that comprise the Water Knowledge Camps program)
    - Field expenses for the teams
    - Northern Water Futures has been renewed for another 3-year period, providing additional support for this work.
3) Water Knowledge Camps ($100,000/year for 3 years)
    - This Global Water Futures funded program will help to ensure community engagement and knowledge exchange between our teams and the community members on whose lands we are working.
    - There will be one camp per year in Tulita (2019), Fort Good Hope (2020), and Deline (2021)
4) Polar Continental Shelf Program ($45,438 for 2018 field work; $64,428 for 2019 field work)
5) University of Guelph – Carolyn Gibson's salary is supported through a prestigious scholarship at the University of Guelph and sample analysis costs for Jess McCuaig's soil carbon analysis is supported by Turetsky's funds at University of Guelph.
6) Government of the Northwest Territories ($150,000 in 2018, $75,000 in 2019)
    - These year-end contributions are helping to support the establishment of this field program and those of Drs. Rudolph and Gray. These resources are helping to support helicopter time to access disturbance features on the landscape. The inaccessible nature of much of the landscape makes this sampling particularly challenging and costly.
7) Wilfrid Laurier University ($15,000) – Jason Paul led the ground ice sampling in the Sahtú in 2019 and will again in 2021. His predecessor Genevieve Degre-Timmons led the effort to understand changes post-fire in forage lichen biomass. They both spent ~25% of their time on this work and their salaries are funded through Baltzer's Canada Research Chair funding provided through Laurier.

Spending to date

2017/18 funding - $50,000
2017/18 expenditures - $11,557 Husky site visit and Kristen Bill salary)

2018/19 funding - $50,000 + 2017/18 fund balance forward of $33,443 (total funds available = 83,443)
2018/19 expenditures - $59,841 (Field costs and Kristen Bill salary)
2019/20 expenditures – Total expenditures: $49,273: $808 (Materials and Supplies); $42,038 (Helicopter charters to support 2019 field sampling campaign; $6426 (Overhead)

The Contribution Agreement for this project began in July 2017, too late to start a 2017 field season. As agreed upon, we were underspent on these ESRF funds in 2017 and 2018. We are now largely on track for spending but we will not spend any ESRF funs in 2020/21 due to COVID-19. We will save our remaining allocation for the 2021 field season described above.