Annual reporting for GNWT Environmental Studies Research Fund – 2018/19

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 (mrt@uoguelph.ca)

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 2018/19 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
Anna Coles	Postdoctoral Fellow	Northern Water Futures
Carolyn Gibson	PhD student	University of Guelph
Kirsten Bill	MSc student	ESRF
Ana Sniderhan	Research Associate	Global Water Futures
Genevieve Degre-Timmons	Research technician	Wilfrid Laurier University
Emily Ogden	MSc Student	Northern Water Futures
Alexis Jorgensen	MSc Student	ESRF

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. During our field sampling in 2018, we were fortunate to have Elder Leon Andrew join our team during field reconnaissance. We plan to do the same in 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 co-led a proposal to Global Water Futures to obtain resources to develop on the land camps that will lead to improve knowledge sharing between researchers and community members. The first of these camps will take place in July 2019 and will involve members of our ESRF team.

Figure 1. Thermokarst and fire site reconnaissance with Elder Leon Andrew during the summer of 2018. Photos courtesy of Carolyn Gibson.

Research progress

Below, we provide updates on three distinct though interconnected components of this project:

1) Thermokarst vulnerability assessments
2) Post-fire forage lichen forage recovery
3) Post-fire soil recovery

During the summer of 2019, we will begin to bring these pieces together by completing our sampling of vegetation and soils recovery in areas disturbed by wildfire and by conducting parallel sampling in regions that have been identified as vulnerable to permafrost thaw. Combined, this information will allow us to better predict how changes in disturbance frequency will affect caribou habitat quality through changes in the recovery of soils and vegetation.

Thermokarst vulnerability assessments

As outlined in our 2017/18 reporting, we plan to use the following framework to evaluate thermokarst vulnerability in the Sahtú region.

***Figure 2**. Examples of thermokarst features in the Sahtú region. Photos courtesy of Carolyn Gibson.*

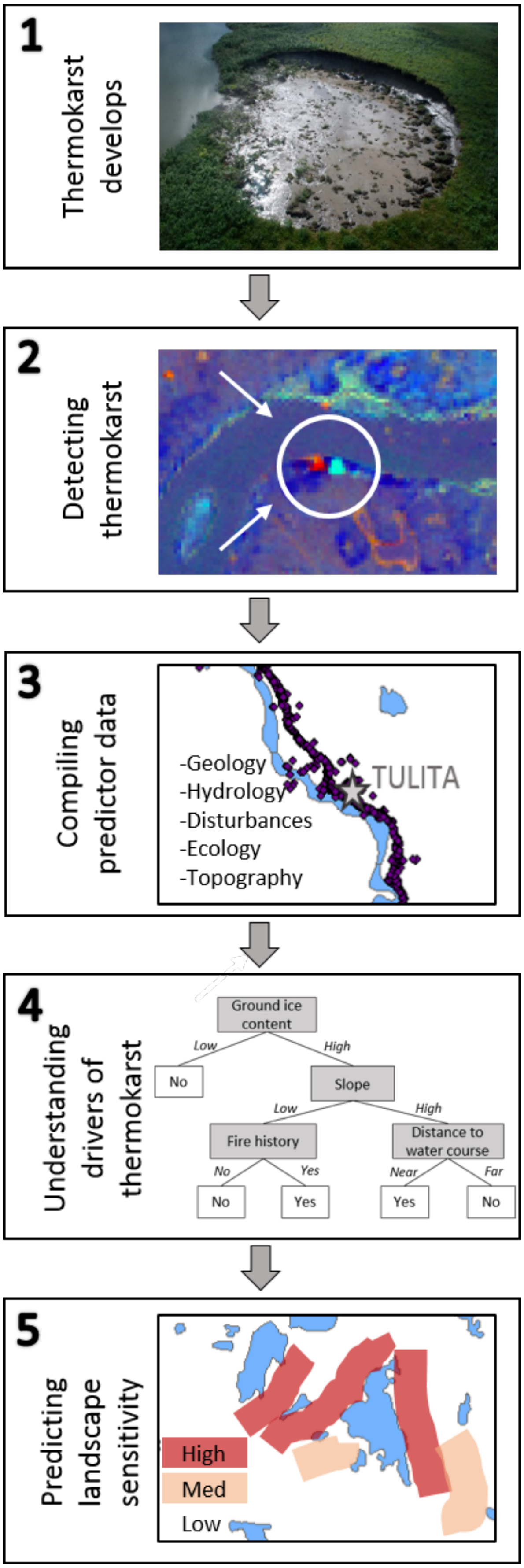


Figure 3. *Work plan connecting remote sensing tools with geotechnical and new field-based data collected during this project. Panel 4 demonstrates the decision tool that will be used to assess vulnerability to changing permafrost conditions. See 2017/18 report for details on geotechnical and RS data sources.*

To date this part of the project has completed field reconnaissance during which features that were not identifiable on the remote sensing imagery were ground truthed. From August 1 – 20, the team was in Norman Wells, NWT visiting areas that had recently thawed and experienced wildfire. These field visits also included site assessments that involved collecting data on numerous biophysical indicators (vegetation composition, soil depth and properties, water sampling). Twenty-seven sites were visited that varied in ecosystem type, permafrost conditions, and disturbance history. Using the ArcGIS collector App, field sampling sites were geolocated and actively mapping to help with interpreting remote sensing images. This work was complemented with aerial surveys to capture images of sites from above to link on-the-ground conditions to spectral characteristics in photos and remotely sensed images.

With this ground truthing in hand, we have been mapping areas vulnerable to permafrost thaw using the ArcGIS collector app. This work applies the field-based knowledge and data to help delineated permafrost peatlands (areas highly susceptible to permafrost thaw; e.g., photos in Figure 2). In October 2018, a second field trip was completed to measure end of season thaw depths at a number of sites – data that is imperative to track yearly changes in permafrost conditions. The end goal of this work is to improve accuracy and resolution of the map presented in figure 4. We are currently at step 2 of this process and the methods to be used for this are provided in figures 5-7.

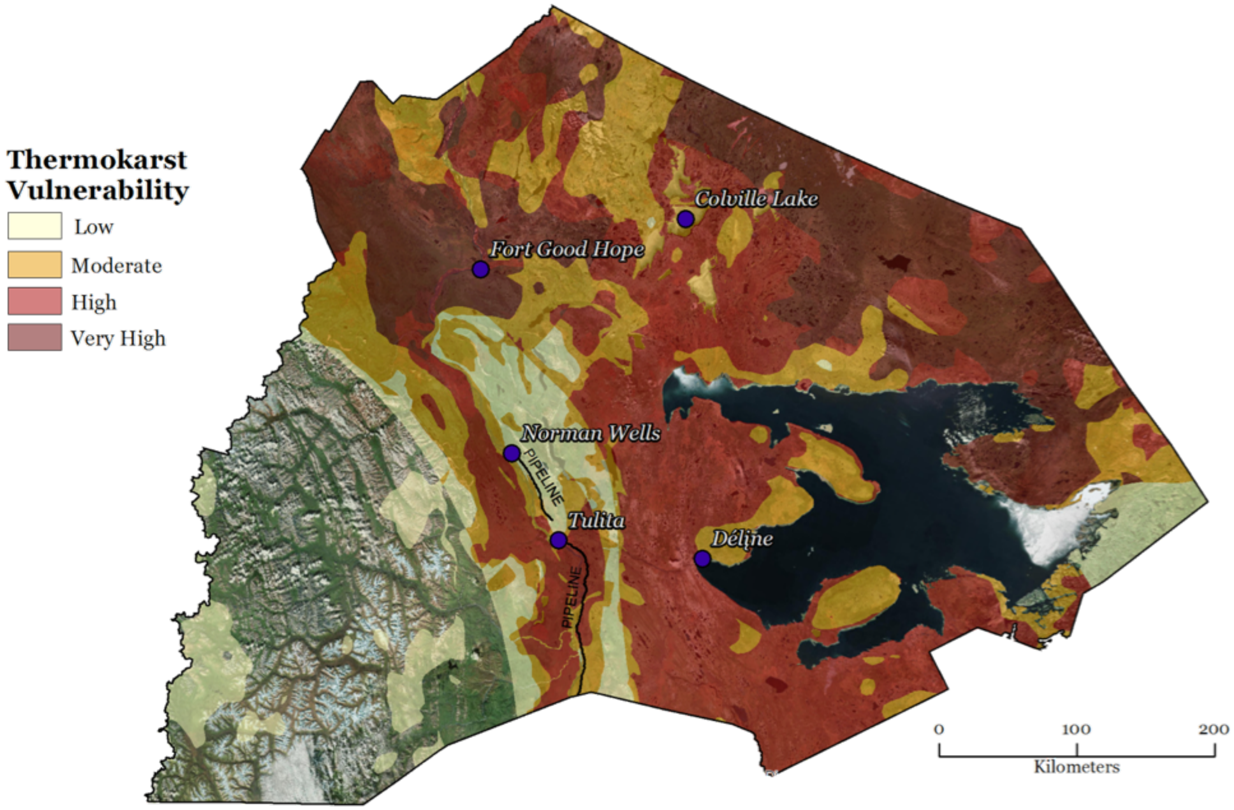


Figure 4. *Thermokarst vulnerability map based on Olefeldt et al. 2016. The data we are collecting and analysis we are conducting will produce a finer scale and more accurate vulnerability map for this region.*

Broad scale thermokarst mapping in NWT

Using the broad-scale thermokarst inventory techniques of Kokelj et al. 2017, Fraser et al. 2018 and the methodologies of Segal et al. 2016, permafrost peatlands will mapped using a 15 by 15 km grid system within the Taiga Plains ecozone of the NWT (Figure 5). Each 15 by 15 km grid will be broken in smaller grid cells where presence/absence of a permafrost peat plateau will be recorded. Percent coverage of permafrost peatland in each cell will be calculated as (*number of 'present'/total number of tiles*)**100.*

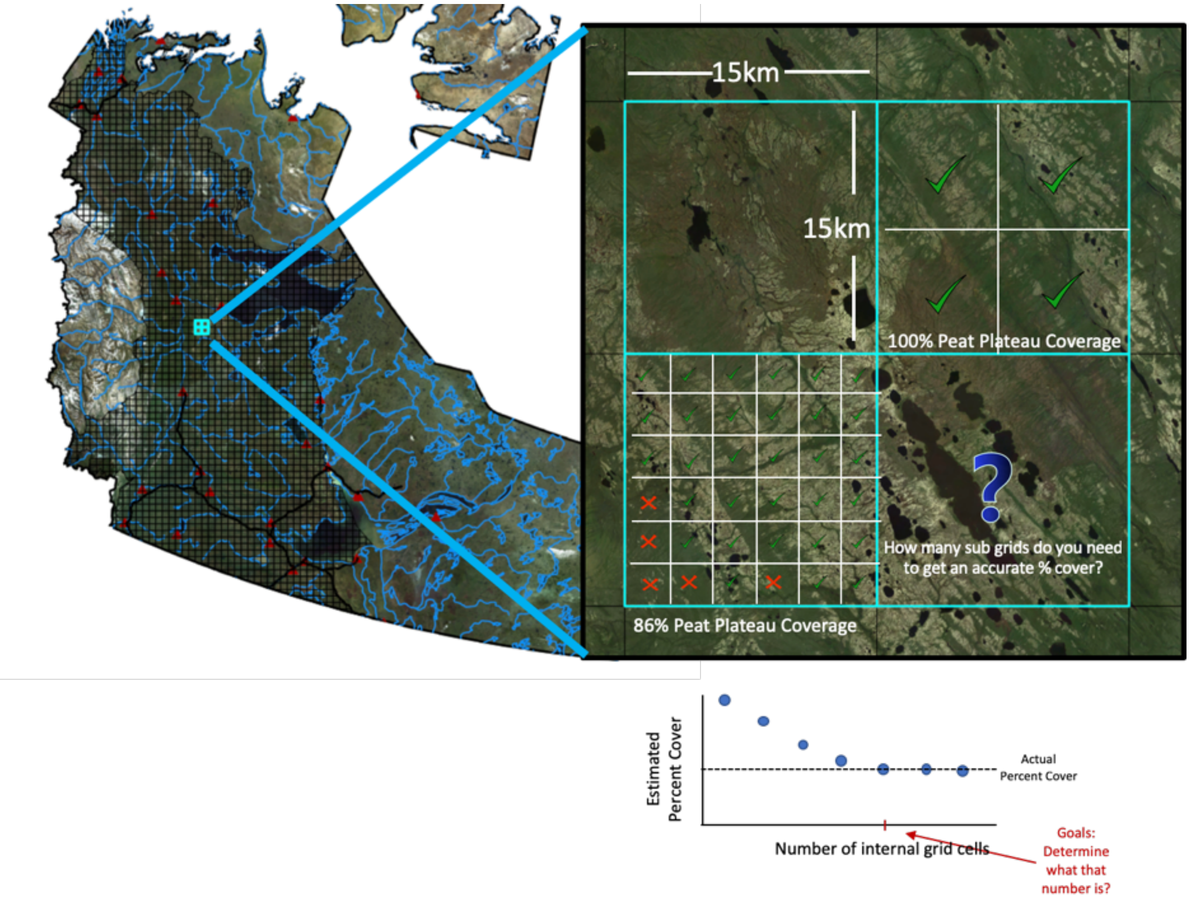


Figure 5. *Proposed mapping methodologies for the NWT Thermokarst Collective, Organic Terrain mapping group.*

<u>Fine scale thermokarst mapping in the Sahtú</u>

To determine how many sub grid cells will be needed within the 15 by 15 km grid test areas will need to be conducted. These will be occurring around in a 70 x 70 km grid around Norman Wells and Tuilta. During this process, peat plateaus will be manually digitized peat plateau within the area of interest. This will provide an ‘true’ estimate of peat plateau area around these communities. Using this ‘true’ area, I will then determine the area the number of sub grid cells to get an accurate estimate of the true are using presence/absence. I will then start by creating the initial grid cell into four 7.5 by 7.5 grid cells, doing presence/absence, and continually break the grid cell into smaller and smaller sub-cells, doing presence/absence, until I can accurately represent the true permafrost peatland area using presence/absence grid cells (Figure 5).

The final product will provide a spatial distribution of permafrost peatlands, and will be coupled with work described above to make statements about the fate of permafrost peatlands within the NWT in the next 50 – 100 years.

Progress to date:

Manual delineation of permafrost peat plateaus has begun around Norman Wells using supervised classification (Figure 6).

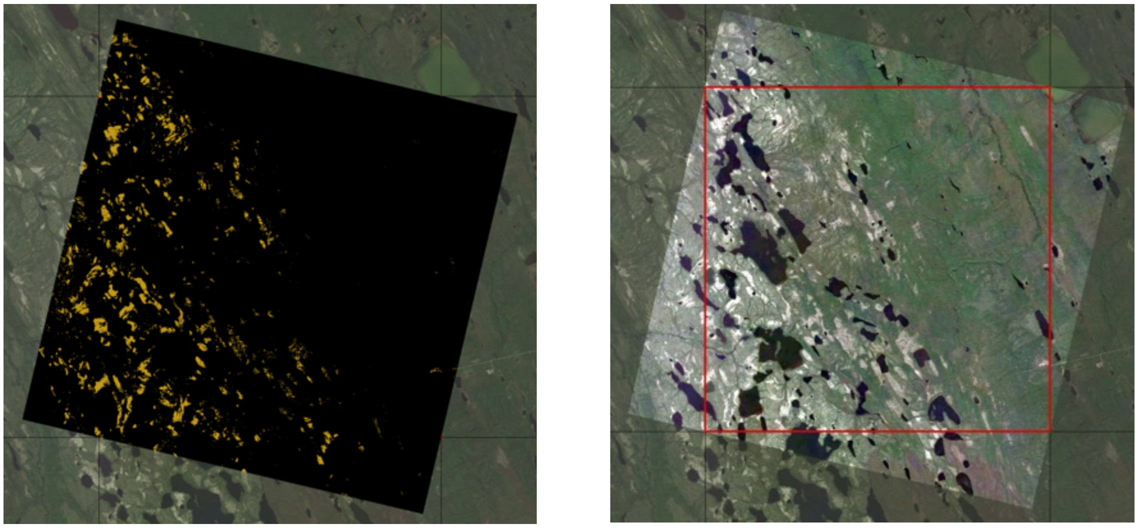
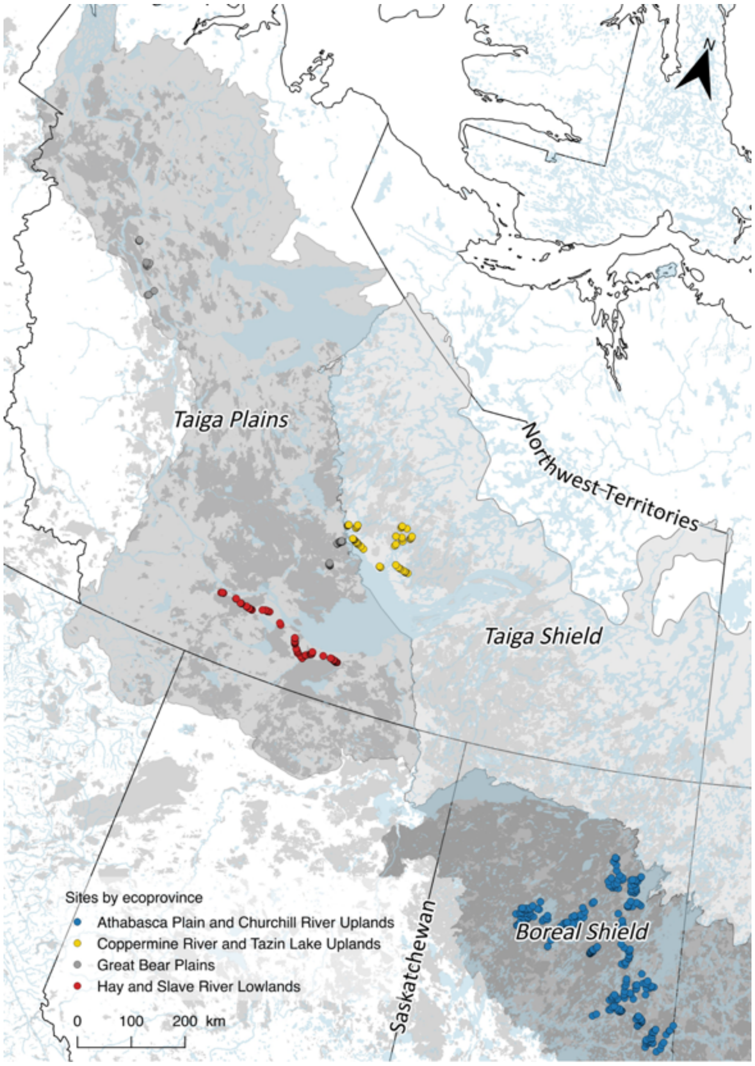


Figure 6. *Example supervised classification of permafrost peat plateaus 50 km east of Norman Wells. Yellow represents permafrost peatlands susceptible to wetland thermokarst formation.*

Chronosequence sampling of lichens, ground vegetation and soil recovery following fire



During the summer of 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 7). 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.

Figure 7. *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. Characteristics of NWT-based sites are provided in Table 1.*

Table 1. Summary the plot characteristics for young and mature stands across ecozone. Young site averages were measured in 1 year old stands after the 2014 fire year, whereas mature averages were measured in stands that burned prior to 1965 and in 1969 (Sahtú).

Ecozone		**Plains**		**Sahtú**		**Shield**	
Successional stage		**Young (2014)**	**Mature**	**Young (2014)**	**Mature**	**Young (2014)**	**Mature**
Elevation		237 ±1.97 (143)	236 ±4.97 (96)	317 ±5.17 (6)	122 ±3.10(6)	302 ±7.17 (90)	215 ±5.57 (74)
Proportion of Drainage classes	Dry	40% (63)	25% (25)	NA	NA	45% (39)	53% (75)
	Moderate	34% (54)	24% (23)	67% (4)	50% (3)	29% (14)	18%(14)
	Wet	25% (63)	51% (49)	33% (2)	50% (3)	29% (32)	29% (22)
Average peat layer depth (cm)		13.36 ±1.20 (143)	34.46 ±0.90 (96)	16.30 ±2.40 (6)	23.20 ±2.04(6)	13.28 ±1.54 (90)	13.45 ±1.28 (74)
Black Spruce basal area (cm^2 m^{-2})		7.83 ±0.70 (136)	9.86 ±0.85 (97)	5.87 ±0.52 (97)	4.53 ±0.93 (6)	5.24 ±0.55 (89)	5.83 ±0.75(75)
Jack Pine basal area (cm^2 m^{-2})		6.04 ±0.67 (136)	5.11 ±0.96 (97)	0 (6)	0 (6)	0.92 ±0.27(89)	3.49 ±0.61 (75)
Deciduous basal area (cm^2 m^{-2})		0.049 ±0.03 (136)	0	0	0	0.0006 ±0.0006 (89)	0
Average fire free period		41.74±2.38 (358)		23.5±6.78 (12)		41.38±2.7 (230)	

Lichen biomass recovery following fire

At all of our sites, we measured the area and depth within fixed plots for each species of lichen present at the sampling site. At a subset of these sites, we also destructively harvested small lichen plots in order to develop allometric relationships between *in situ* lichen volume estimates (lichen depth x area) and mass-based lichen volume estimates. We found strong relationships between these two measures that did not vary by ecoregion (Figure 8). This finding allows us to extrapolate our allometries to sites in which we have only area-based estimates of lichen abundance.

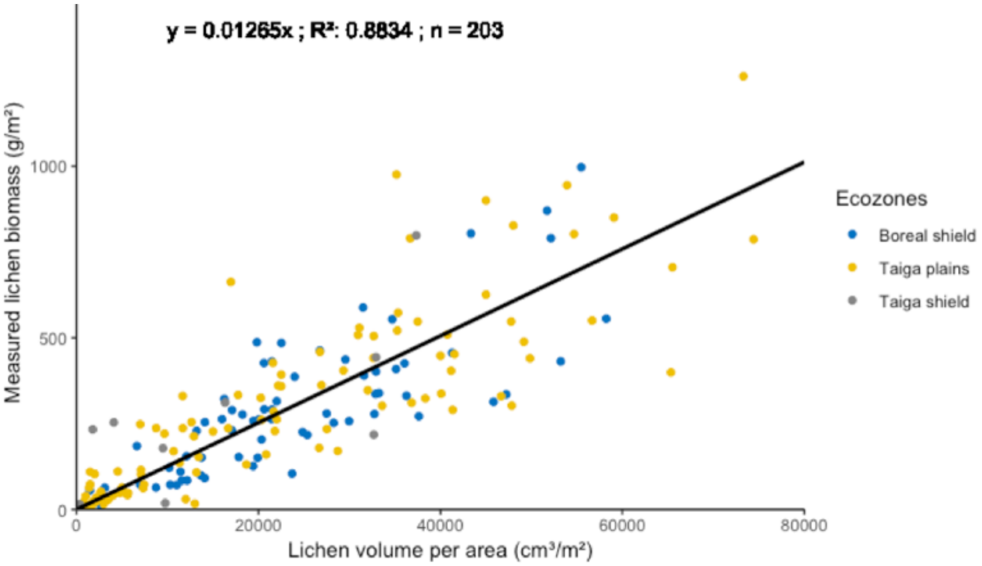


Figure 8. *Allometry for a forage lichen (Cladonia sp.) across ecozones depicted in Fig. 7. The relationship between in situ lichen volume (area x depth) measured in field plots vs. true lichen biomass measurements (mass-based) show a strong positive relationship and no difference between ecozones allowing us to apply this allometry to all field samples regardless of location. Gruel, Degre-Timmons et al. in prep.*

Using these allometries, we scaled our plot-based estimates of lichen abundance to estimate lichen biomass recovery times in different stand types following fire in these ecoregions. Briefly, we see a strong latitudinal gradient in maximum lichen biomass volume as well as the rate of recovery with more southerly locations having faster recovery and greater maximum lichen biomass (Figure 9).

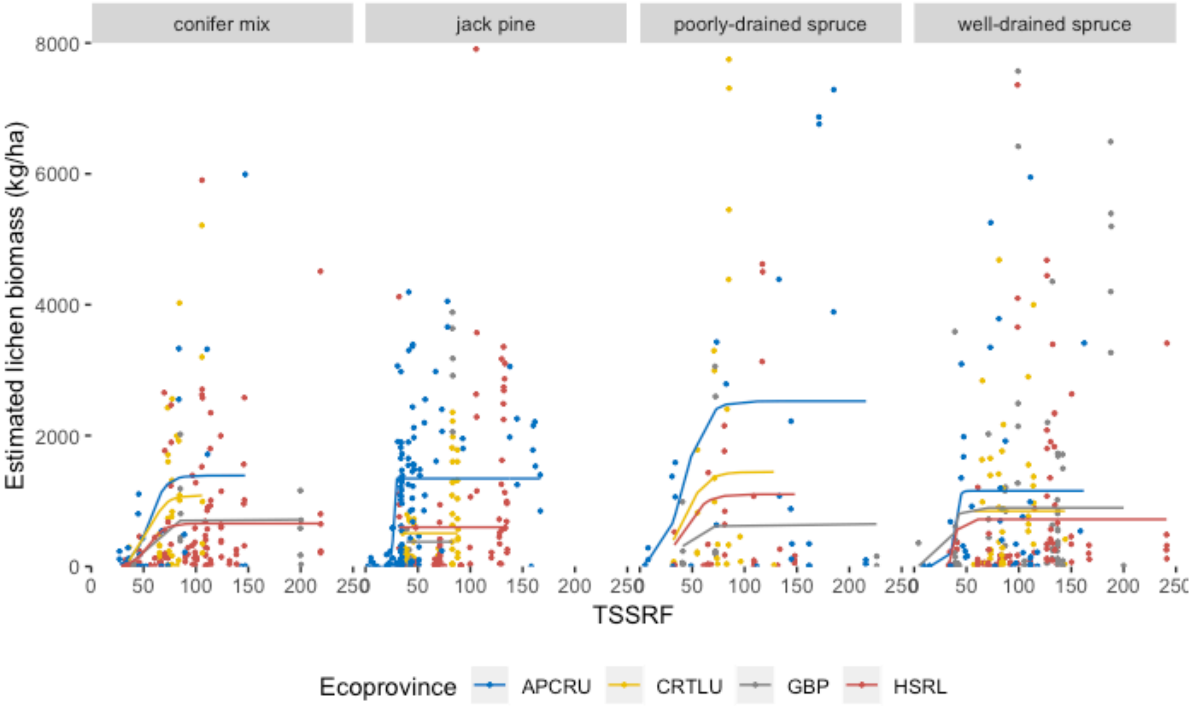


Figure 9. *Lichen biomass estimates for the ecoregions depicted in Figure 4. APCRU = Saskatchewan; CRTLU = Dehcho; HSRL = Tlicho; GBP = Sahtú + sites to the west of Gameti. Estimates are broken down by land cover classes. We see the importance of poorly drained spruce in supporting high maximum lichen biomass accumulation across all regions.*

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Recovery of soils following fire

More than 1km of soil has been sampled across our sites in the NWT, with a total of 3,300 soil monoliths processed for soil texture, bulk density to model carbon recovery. Soil horizon type by peat layer thickness over the post-fire recovery period. Dry sites (xeric) have the shallowest peat thickness, whereas the wettest sites (sub-hygric) have deeper soil profiles. Horizon type in the profile will change depending on the moisture and recovery time (Fig 10). Mixed effects modeling techniques were used to understand soil depth recovery over time after wildfire activity in the three regions. Time-since-fire, soil drainage, non-vascular plants, ecozone, jack pine and tree stand type all were significant explanatory variables in predicting peat layer thickness after fire. Peat layer recovery after wildfire is more rapid in the driest sites comparative to wetter sites that start out with greater residual organic layer following fire (Figure 11). Overall, the Taiga Plains had the greatest variation and deepest soils compared to the other ecozones (Figure 12). Time-since-fire had a strong correlation with black spruce and non-vascular recovery in all ecozones, respectively (Spearman's, $p<0.05$ and $p<0.001$).

Average fire-free-period are similar across the Plains and Shield ecozones, with fire-free-period ranging from 1-241 and 1- 275 years, respectively. Proportion of drainage classes varied across ecozone, with the majority of mature sites being wet for the plains and Sahtú regions, whereas the dry sites dominate mature sites in the shield (Table 1). In the Plains, 17.1% (n= 18) of the moderately wet sites had ice close to the surface (<2m deep) compared to 13%(n=6) in the Shield. A larger proportion of wet sites had ice in both ecozones 46.7% (n=72) and 78.8% (n=56) in the Plains and Shield. Overall, 3.35 kg C /m^2 of SOL was combusted from the 2014 sites. The slopes for soil recovery in our mesic/xeric sites were approximately 0.07 kg C /m^2/ year meaning that on average it will take 48 years for soils to recover to pre-fire conditions in these sites.

In moderately wet sites, black spruce dominated 62.8% (n= 66) of sites in the Plains compared to 51% (n=22) of sites in the Shield. In peatlands, 48.7% (n=75) of Plains sites were dominated by black spruce compared to 73%(n= 52) in the Shield. A smaller portion of the sites were dominated by deciduous trees species including balsam poplar (*Populus Balsamifera*), paper birch (*Betula papyrifera*), and trembling aspen (*Populous tremuloides*) (Table 1). Across moderately wet sites deciduous trees dominated fewer sites in the Plains 18% (n=19) and Shield ecozones 34.8% (n= 15), compared to 85.7% (n=6) in the Sahtú ecoregion. Despite the smaller sample size within the Sahtú this mean deciduous composition was found to be fairly representative of the typical forest composition in this region.

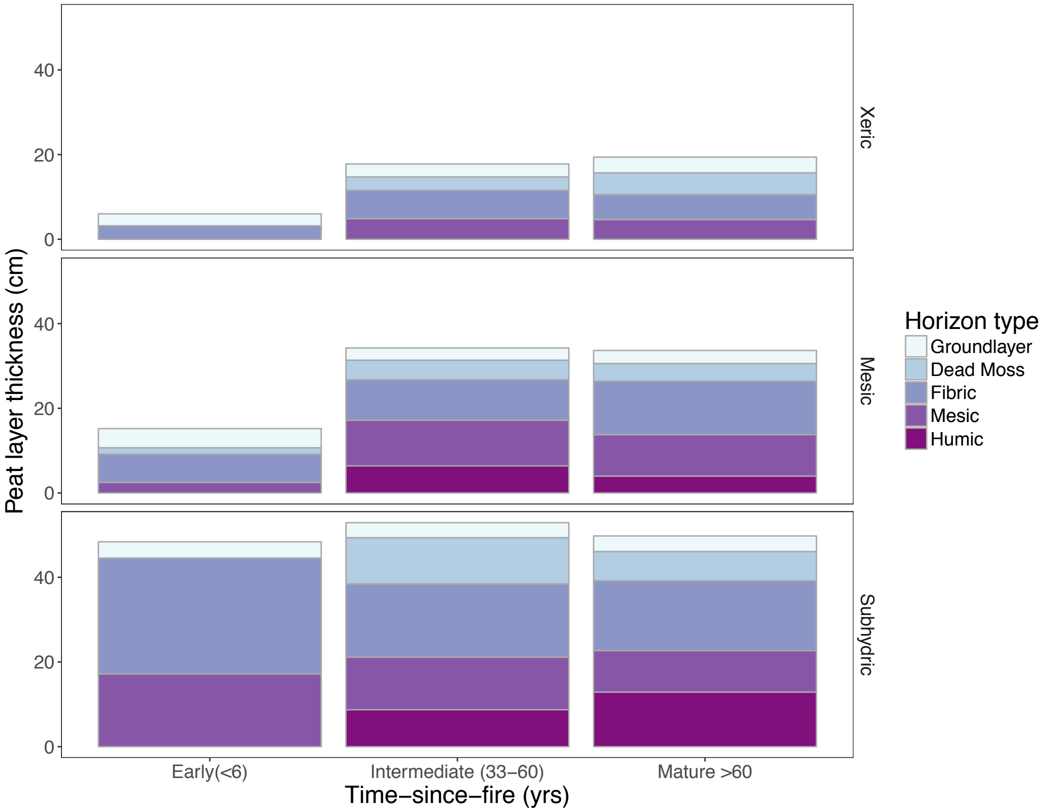

Figure 10*. Soil horizon type by peat layer thickness over the post-fire recovery period. Dry sites (xeric) have the shallowest peat thickness, whereas the wettest sites (sub-hygric) have deeper soil profiles. Horizon type in the profile will change depending on the moisture and recovery time.*

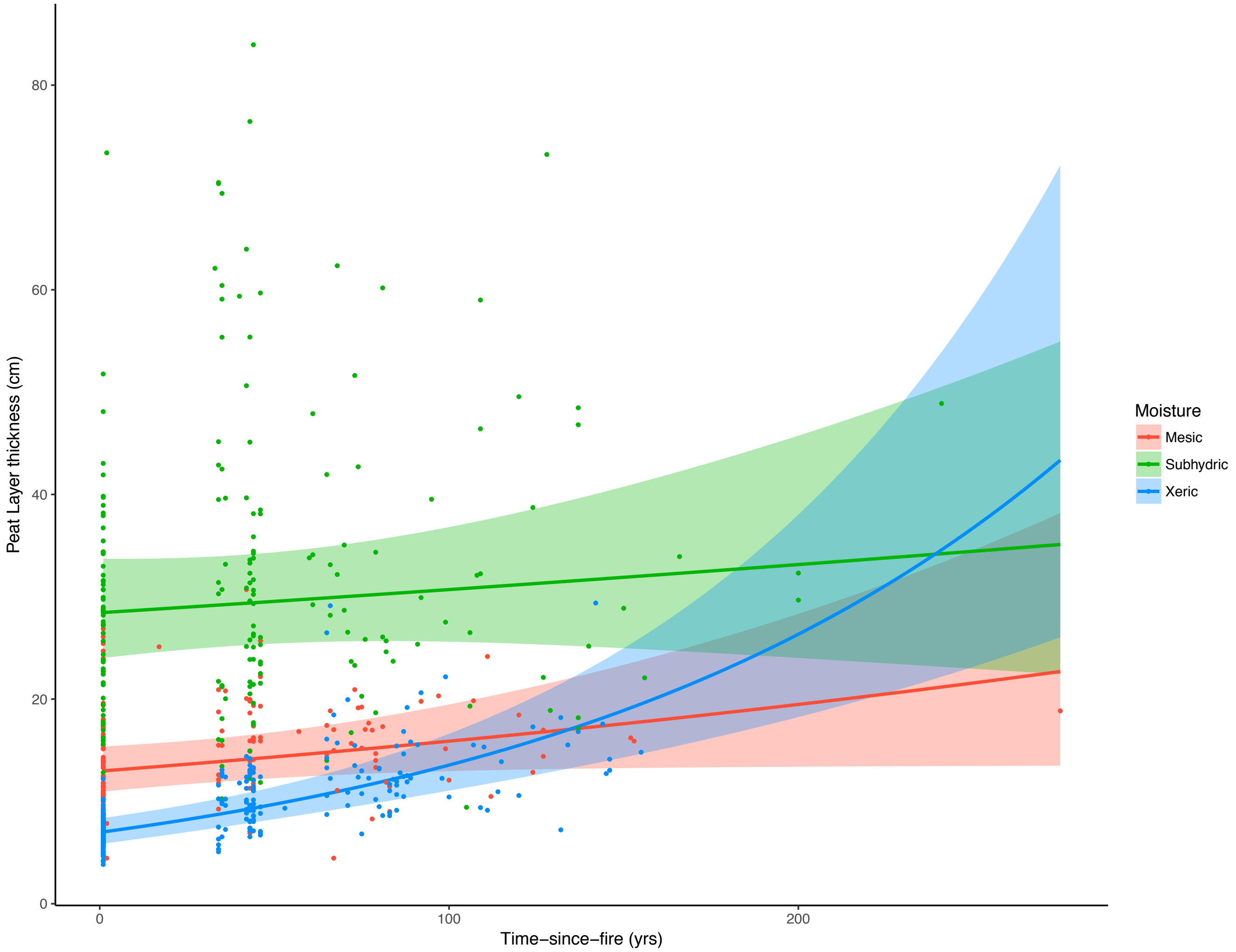

***Figure 11**. Peat layer thickness modeled by time-since-fire (years) across different soil drainage classes. This is using the best predictive model found so far: Peat layer thickness predicted by time-since-fire, drainage class, nonvascular plant groups, ecozone, basal area of Jack Pine and tree dominance (graphed in R package: Visreg).*

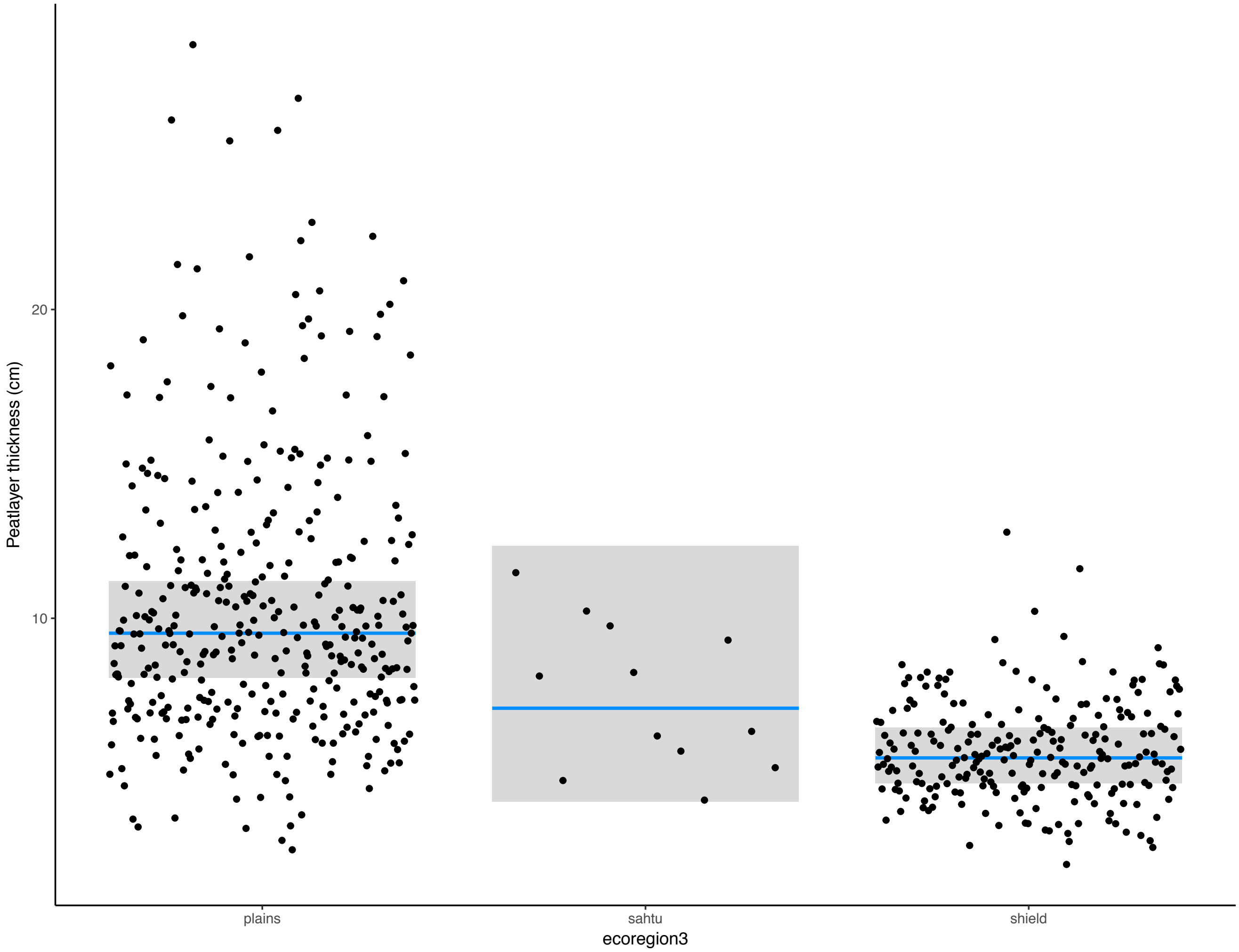

Figure 12*. Peat layer thickness modeled by ecozones using time-since-fire median of 42 years and the driest sites. Note: these values have been back-transformed from cube transformed depth data (graphed in R package: Visreg).*

Next steps:

In the coming summer, we will focus our efforts on expanding the sample size to understand vegetation and soils recovery following fire in the Sahtú. We will also work to better characterize the habitat quality in parts of the landscape vulnerable to permafrost thaw (e.g., lichen covered peat plateaus as shown in Figure 13). These new field data will allow us to better understand recovery of important caribou habitat features following wildfire and the value of areas vulnerable to thermokarst as caribou habitat.

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).

Figure 13. *An aerial image of a lichen-filled peatland near Norman Wells, NT. Photo courtesy of Carolyn Gibson.*

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, planned for July 2019

2) Yr 1: Research team involvement in the Sahtú Environmental Monitoring Research Forum meeting in Tulita to engage the community further in the proposed research

- Completed

3) Yr 1: Review and synthesis of literature, data, and images on permafrost, fire, and caribou habitat in the Sahtú

- In progress – This will form part of incoming MSc Alexis Jorgensen's thesis project.

4) Yr 1-3: Field surveys and analysis of data to establish relationships between fire, permafrost, and vegetation

- Successful field season in 2018 and a second field season in planning for 2019

5) Yr 2-3: Point based photointerpretation of change characteristics

- In progress – PhD Carolyn Gibson's work

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 (see figure 4) as part of PhD Carolyn Gibson's work

7) Yr 3-4: Produce spatially explicit information on post-thaw landscape change and subsidence in critical caribou habitat

- 2019 fieldwork will help to support this goal.

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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
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'ıl̨ ı̨Forum 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
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.
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. In particular, 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) – Genevieve Degre-Timmons led the fire scar field sampling in the Sahtú in 2018 and has been coordinating the effort to understand changes post-fire in forage lichen biomass. She was spending ~25% of her time on this work and her salary is funded through Baltzer's Canada Research Chair funding provided through Laurier.
8) We are coordinating field logistics with the teams of Drs. Rudolph and Gray to ensure maximum output and efficiency from all sampling efforts and the integration of these different teams to promote interdisciplinarity in the research program and results.

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)

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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. We continue to be underspent owing to the fact that:

1) Many of the HQP recruited to conduct the research are funded from other sources meaning we have only had to pay salary for Kristen Bill's to date, though an incoming MSc student (Jorgensen) will draw salary from this fund.
2) We received PCSP funding and year-end funds from the GNWT that helped to support the 2018 field season.
3) Our first field season (2018) was relatively short but critical for the ground truthing of thermokarst features. These data will help support sample site selection for assessing the value of sites vulnerable to thermokarst for caribou habitat, sampling which will occur in summer 2019.
4) The coming field season will be much more substantial (1.5 months), which will result in the spending down of the remainder of these surplus funds.