Progress Report Template
2022-2023

1. Name of Lead Network Investigator(s): Robert Way

2. Project ID and Title: P20-Climate Vegetation Cryosphere Interaction

3. General advancement of project objectives:
   a. As planned

Comments (provide explanations if b. or c. selected):
Progress has continued In line with expectations.

4. Project Abstract

Provide an updated, concise, plain language abstract that briefly summarizes the project background, approach, results, outcomes and impacts.

Across Labrador and northern Québec (including Nunavik, Nunatsiavut, Nitassinan and NunatuKavut), rapid regional warming observed over the past several decades has significantly impacted the quality of life for Indigenous Peoples and northerners. Similarly, thawing of regional permafrost, hydrological changes and vegetation growth may have future impacts on infrastructure development, natural hazards, archaeological sites, and cultural keystone species such as caribou and berry plants. Prior studies have shown that increasing shrub height and density can degrade permafrost by changing how snow accumulates across the landscape, which alters surface energy fluxes. This project aims to improve our understanding of how observed and projected changes on plants, trees, snow cover, and permafrost will interact, and how this may impact people and northern ecosystems. Combining field observations, remote sensing and numerical modelling will allow us to bridge spatial scales and predict how landscapes in Nunatsiavut, Nunavik and NunatuKavut will respond to future environmental change. Focusing on snow as the key link between vegetation and permafrost, we are exploring how local climate and geomorphology create heterogeneity in coastal landscape responses to climate change.

Early project results have included development of a satellite-based method for mapping hotspots of environmental change in the Torngat Mountains National Park (TMNP) (Nunatsiavut) and Kuururjuaq National Park (KNP) (Nunavik). These results, in combination with field measurements, implicate enhanced shrub growth as the dominant source of ecosystem change. Notably, shrub growth was most prominent at low elevation where permafrost is inferred to be the warmest and thus most sensitive

to change. Future changes to permafrost are inferred to be linked to snow cover variability and local ecosystem characteristics. To explore these topics, we have established two research basins (Nain Bay Hills and Pinware River Hills) where high resolution measurement and modelling of ecosystem properties (snow, vegetation, soil) is ongoing across 400 m by 400 m field sites. Historical changes in climate conditions including snow cover are being explored with the ClimEx ensemble to separate out natural and anthropogenic influences on regional climate variability.

This interdisciplinary project will allow us to better assess habitat vulnerability to future environmental changes, permitting regional policymakers to make more informed decisions on adaptation, management and infrastructure initiatives. Improved understanding of the connections between snow, trees, plants and permafrost is highly transferable and will give other communities access to conservation and planning tools needed to better manage changing northern landscapes due to climate change.

5. Research Objectives

In bullet form, provide the overarching objectives of your project, as well as its specific objectives.

1. To implement a long-term monitoring program that will examine how culturally important species will be impacted by climate change and characterize plant biodiversity and structure across vegetation and topographic gradients in coastal environments;

2. To maintain ongoing open-top chamber warming experiments in the Torngat Mountains and continue long-term monitoring of tundra vegetation change in northern Labrador using repeat ground photography, satellite remote sensing, aerial photography and terrain analyses;

3. To summarize and assess the accuracy of climate model simulations (ClimEx) over the historical period for snow cover, surface-air temperature and precipitation for the IRIS-4 region and to use ClimEx to explore the role of natural climate variability in recent climate changes observed over the IRIS-4 region;

4. To characterize temporal and spatial variations in snow distribution across coastal Labrador and Nunavik by analyzing existing climate observations and through development of a low-cost methodology for measuring snow characteristics in real-world environmental conditions;

5. To model snow redistribution and density variations across vegetation and topographic gradients in coastal environments and to evaluate how geomorphology modifies snow impacts on ground temperatures;

6. To develop and evaluate a theoretical model for snow, vegetation and permafrost feedbacks using one- and two-dimensional thermal modelling and to use this approach to characterize permafrost sensitivity to historical and future thaw due to changes in vegetation and snow cover in coastal Labrador and Nunavik;

7. To assess how predicted environmental changes will cumulatively impact habitat for keystone species including caribou and berry species in coastal Labrador and Nunavik.

6. Project Research Results and Impacts

Describe the Overall Research Results and Science Highlights, and describe their impacts. Please relate these to the stated Project Research Objectives in Section 5, when applicable.

Research Results & Science Highlights	Impacts (for science, northerners, policy, outreach, etc.)
In Torngat Mountains National Park, we collected images covering 2 HA to 52 HA blocks at four sites (Komaktorik River; Ramah Bay; Nakvak Brook; Torr Bay) using a highly specialized multispectral remotely piloted aircraft (RPA). Three of these sites (Ramah Bay; Nakvak Brook; Torr Bay) were also imaged with a standard RPA for derivation of high resolution imagery and topographic information. **[Objective 1]**	The resulting images will be used as baseline conditions for reflying in subsequent years to better understand the variability in tundra vegetation change at broader scales than are possible with plot data.
Lichen coverage across sites: For PL PhD thesis: Vegetation assessments comparing PRH site to Cartwright and NBH sites indicated that lichen forage availability is much higher in PRH (87.1 dm^3/m^2) where caribou herbivory pressures have been absent compared caribou present sites, including Cartwright (12.4dm^3/m^2) and NBH (5.4 dm^3/m^2).	Based on the low quantity of lichen availability in caribou occupied sites (without a strong understanding of the magnitude of usage) we can infer that caribou in these areas must exert much more energy and time to acquire the same amount of food, especially when selecting for lichens. However, even among vascular plants, the ones that are dominant in NBH are not

These findings were presented at the ArcticNet conference in December of 2022. We also found that, of the species present (vascular plants, bryophytes and lichens), the ones that were most abundant in Cartwright and NBH were not preferred by caribou, whereas in Pinware, the preferred species were the most abundant. **[Objective 1 & 7]**	necessarily preferred by caribou. This can be concerning if it is representative of the larger home ranges of caribou if they are generally forage scarce environments, even after a relatively long release of herbivory after population declines.
For MSK undergraduate thesis (to be submitted in April 2023): Shrub growth decreases ground lichen abundance, which becomes more pronounced as shrub cover increases. Conversely, early findings show that lichen diversity may not be immediately sensitive to new shrub growth. These findings are being supported by comparative ground plot assessments near shrub and underneath shrub. The shrub size and biomass is being estimated using hand-held LIDAR and PIX4D matic. **[Objectives 1 & 7]**	Increased understanding of plant and lichen diversity in response to continued shrubification of these coastal landscapes. These results are important for understanding and contextualizing potential change in caribou forage. Based on our findings, it seems possible that important lichen species may continue to persist under long term shrub cover, which can be an important ecological refugia in the event of abrupt land use change, allowing these lichens to recolonize disturbed lands more quickly than if they were eliminated from these land cover classes.
Deployed 22 data loggers to restore all the observations at the long-term tundra warming experiment, with open-topped chambers, in Nakvak Brook. Many soil temperature observing sites had been discontinued during the pandemic but we redeployed more than were present pre-pandemic. **[Objective 2]**	These long-term data help to contextualize the role of climate variability and change in different tundra ecosystems across wet and dry tundra sites. These results can be used to inform future monitoring activity by Parks Canada by providing novel long-term perspectives on biotic and abiotic changes at these high-elevation tundra sites.
Manuscript reporting results of long-term (>13 years) vegetation monitoring currently in preparation (Davis et al.). Overall, lichen, mosses and shrubs were sensitive to the experimental warming. In terms of abundance, evergreen shrubs decreased in dry plots while deciduous	These results will be used by Parks Canada to help identify important variables to monitor at tundra sites. Results will also be useful for understanding the species-specific changes that are being reported at broad spatial scales (e.g.. Davis et al., 2022) and will

shrubs increased in wet plots. Both deciduous shrubs and forbs increased in height in dry and wet plots. Also interesting was that wet sites became significantly drier over this 13-year period. **[Objective 2]**	provide valuable insight into how future changes will manifest.
MSc student Dominic Morin submitted his final thesis in April 2022, and a paper based on his work is under development. Results from the Canadian Regional Climate Model version 5 (CRCM5) have emphasized the predominant role of the North Atlantic Oscillation as a natural mode of variability that strongly affects temperature and precipitation variability in the historical period over northern Québec and Labrador , hence allowing to better quantify the uncertainty related to historical climate trends. **[Objectives 3 & 4]**	CRCM5 evaluation against multiple reference datasets have shown that model generated climate series could be used to better understand historical climate variations related with temperature, precipitation and snow cover. This is especially important in the context of the important lack of observational data in northern regions. These regional model outputs could also potentially be used to drive different types of impact models in order to help northern communities to cope with current climate variability. Finally, CRCM5 evaluation allowed us to increase confidence in future climate projections of CRCM5 over northern regions, as done in the second part of the project led by MSc student Léandre Houde-Labrecque.
MSc student Léandre Houde-Labrecque has started his research project in May 2022, and will be assessing future changes in climate variability in northern Québec and Labrador. Building on earlier work evaluating CRCM5 by DM, we are using large ensembles of CRCM5 to characterize climate variability in coastal Labrador in the future. Several aspects of climate variability are currently under investigation, notably the spatio-temporal variability in the patterns of temperature and snow cover, annual cycles of the snow season, as well as present and future co-variability between snow-cover and temperature. **[Objectives 3 & 4]**	Promising results are expected from this project as predicting future changes in climate variability will use large climate simulation ensembles. For Nunatsiavummiut and Nunavimmiut, the impacts of this analysis are related to prediction of future climate conditions. The work demonstrates that across model simulations snow characteristics vary considerably and interannual variability driven by short-term atmospheric oscillations can obscure (or accelerate) changes due to climate change. One consideration as it relates to climate adaptation and climate communication is that we have to be cognizant of the high intrinsic

	variability in the IRIS-4 region and that this variability can both amplify and diminish changes to snow cover to a greater degree than other variables like temperature and ice cover. Our group will be stressing to policymakers that cautious language is needed when discussing the future of snow cover in the region.
The project team prepared a manuscript, led by AF, that developed and evaluated a new method to explore ground surface temperature observations using machine learning and numerical model simulations. AF's method used data from ArcticNet field research basins at PRH and NBH and showed that machine learning can reliably be used to derive snow onset and melt from soil temperature data without the requirement of *in situ* snow observations. AF's analysis also provided insight into the factors influencing snow effects on the ground thermal regime and demonstrated that commonly used methods for deriving snow information from soil temperature have high overall errors. The proposed technique was presented at the 2022 CMOS-CGU-ESC Joint Congress (Forget et al. 2022) and was prepared as a preprint (Forget al. in prep) that is in its final stages of preparation for submission to the open access preprint server EarthArXiv and will also be submitted to the journal *Applied Cold Regions Science and Technology* in March 2023. **[Objectives 4 & 5]**	There are tens of thousands of ground surface temperature loggers that have been deployed across the world for microclimate, ecological and permafrost research. Researchers, especially those working in the north, commonly used these soil temperature observations to estimate snow characteristics. However, there is no consistency across methods and the approaches currently used offer no ability to detect the influences of extreme events on snow cover. The method that AF developed performs better than existing methods and can be applied universally across the North. The method that AF developed has the potential to be used to generate regionally comparable snow information in areas lacking snow measurements all across the north. We believe this approach has immense potential for generating new knowledge on snow-permafrost-vegetation interactions, and for monitoring the influences of snow cover on soil temperature in remote areas.
The project team conducted an analysis, led by RW, which included the development and evaluation of a new algorithm for infilling soil temperature	The development of this novel technique for infilling soil temperature observations will facilitate our project (and other northern projects) to better leverage existing data

observations using numerical model simulations and machine learning. This algorithm was applied to the data collected at the Nakvak Brook, PRH and NBH research basins to test its applicability in challenging coastal Arctic and Subarctic environments. Results from the application of this algorithm to Nakvak Brook are being prepared for a manuscript (Way et al. in prep) that will be submitted this summer for review for the peer reviewed conference paper proceedings for the International Conference on Permafrost (hosted in Whitehorse in 2024). **[Objectives 4 & 5]**	sources for understanding long-term change in soil temperatures, snow characteristics and permafrost in coastal Labrador. Nakvak Brook in particular has the longest sustained observations of soil temperatures in Labrador and the development of this novel technique of infilling will allow the project to evaluate long term changes to ecosystems at Nakvak Brook with greater confidence. The deployment of new data loggers at Nakvak Brook sites where monitoring had been discontinued coupled with this new method should allow us to assess change at these locations where we may have otherwise lost continuous data records. The techniques being developed here in this study are able to be used elsewhere across the Canadian North but more importantly will facilitate analysis of soil temperatures across Labrador in support of a next generation permafrost distribution map currently in development. This map will help guide decision making
The project team prepared a manuscript, led by AF, that evaluated the influence of snow and other ecosystem variables on shallow soil temperatures at both ArcticNet research basins (PRH and NBH). Uncrewed aerial vehicles were used to characterize both study sites prior to logger deployment enabling the full range of ecosystem types and snow climate zones to be sampled at both sites. Evaluation of the early logger results suggest that the PRH research basin cannot sustain permafrost in any ecosystem type under modern climate conditions but that permafrost can exists in tundra and wetland environments at NBH. Other key results include that PRH exhibits	This work has increased our understanding of permafrost distribution in low relief mountains in coastal Labrador and will improve our ability to generate future permafrost mapping products which are lacking or underestimated for the Labrador region. The results from this study also provides insights into the influence of ecosystem characteristics and snow on the ground thermal regime. This improved understanding of the localized impacts on the ground thermal regime will allow for increased accuracy of models for regions in Labrador which has highly heterogenous soil temperatures.

significantly less variability in soil temperatures compared to NBH which may be linked to the presence of permafrost and that presence of permafrost was restricted to the loggers in areas of minimum snow accumulation at NBH. The prepared manuscript will form a portion of AF's MSc thesis and will be submitted to a refereed venue once it has been updated with year two data from NBH. **[Objectives 5 & 6]**	These data will continue to be updated and will support a next generation permafrost hazard map that is being generated for all of Labrador which will help guide community based decision making for the area.
Analysis is underway, led by VC, to explore relationships between local-site properties and the ground thermal regime across coastal-continental and ecosystem gradients in Labrador. Ground surface temperature loggers were deployed at the ArcticNet research sites (PRH, NBH, and Nakvak Brook) and will be compared to the Northern Environmental Geoscience Laboratory's broader network of monitoring sites (n = 141). At each location, field observations are being collected to characterize site conditions, including vegetation, soil and geomorphological characteristics, in the summer while winter field surveys will record snow thickness and density. Early results and maps of the monitoring network were presented by VC at the ArcticNet Annual Scientific Meeting. Next steps will include data cleaning and numerical modelling to analyze the drivers of variability in ground thermal parameters across the entire network. **[Objectives 5 & 6]**	There is limited monitoring infrastructure to study the distribution, thermal state, and vulnerability of permafrost in Labrador. The lack of long-term data on permafrost in the region increases the risks for major infrastructure developments and land-based practices. Challenges in determining the vulnerability of regional permafrost are amplified by ongoing shrub expansion into the tundra. Considerable uncertainty exists over whether shrub expansion will lead to ground temperature warming, through increased snow capture, or cooling, through increased radiation interception. This work will identify areas where ground temperatures are most sensitive to fluctuations in air temperatures and winter precipitation to determine important ecological feedbacks influencing permafrost vulnerability to thaw. The results will help disentangle drivers of near-surface permafrost conditions and contribute to the next generation of accurate permafrost distribution mapping for Labrador.

Analysis has been completed and a peer-reviewed manuscript is nearly complete (AJ) looking at the extent of caribou forage at two sites in Northern Labrador (one site in Torngat Mountains National Park and one site just south of the Park at Torr Bay). Long-term vegetation data from 2009/10 to 2016/21 was used to explore availability and changes in summer and winter caribou forage. Our results suggest that caribou are more likely to be forage limited during the winter than during the summer, and that shrubby summer forage species are becoming more widely available with climate warming. **[Objective 7]**	The impact of this work will help with the management of caribou in and outside of Torngat Mountains National Park by providing seasonal information of forage availability and potentially using these data to inform how many caribou these landscapes can support, from a seasonal forage perspective. The caribou forage rankings developed for this study will be used in future studies to make connections between vegetation data and implications for caribou.

7. Challenges, Changes, or Issues Encountered

This Section should provide information on any obstacles or challenges, if any encountered over the course of your project to date. Please indicate if changes to the composition of your team has occurred.

The year 2022-2023 was largely successful in terms of field activities thus the challenges our project faced were largely due to the prior challenges of COVID-19 and personal situations. Some Winter 2022 field season costs were incurred in 2022-2023 rather than 2021-2022 and at the time of the report (mid-Feb) last year we could not forecast that to be the case. Useful data was collected in Winter 2022 but major delays including road closures because of weather led to our team being stranded in southern Labrador for nearly a week. The combined effect of the delays and the close proximity to financial year end meant that last year's costs were overestimated and this year's costs were previously underestimated though generally we are in line with our expectations as an overall project. The Summer 2022 field season was successful from a research perspective including a return visit to a number of sites in the Torngat Mountains National Park that we had been unable to visit in years prior. However, the lack of extensive fieldwork in the Torngat Mountains National Park during the COVID-19 impacted summers (2020 & 2021) meant that the condition of monitoring stations visited was worse than anticipated. As such, we incurred greater equipment replacement costs than expected for a number of sites but we tried to mitigate this using funds from other sources as we had not budgeted that much for equipment this fiscal year.

Finally, our team had three highly valued HQP leave this year for full time (northern-related) positions. Dr. Emma Davis, a Weston Postdoctoral Fellow working in the Trant Ecological Legacies Lab, began working as an Ecosystem Science Manager for the Government of Newfoundland and Labrador in Fall 2022. Anika Forget (MSc Candidate, Northern Environmental Geoscience Laboratory) began working as an Ice Specialist at the Canadian Ice Service in Fall 2022 and Alexandra Johnson (MSc awarded in Summer 2022, Trant Ecological Legacies Lab) began working as an Environment Officer with Indigenous Services Canada in Summer/Fall 2022. As a project team, we are very happy with the success that these HQP have had in acquiring these positions. Nevertheless, as one could expect the progress on manuscripts relating to their work has been slower than when the HQP were singularly focused on the ArcticNet supported research program. This has impacted our project's overall productivity in 2022-2023 but these manuscripts are expected to be submitted throughout 2023.

8. Publications, Knowledge Mobilization Activities and Impacts

Include a full list with a brief description of knowledge sharing activities to disseminate research results including, but not limited to: posters, oral presentations, fact sheets, consultations (even if virtual), events, coverage in the media, participation in senate/parliament hearings, podcasts, science briefs.

a) Peer reviewed contributions

Published

1. Rixen et al (incl. Way, R.). (2022). Winters are changing: snow effects on Arctic and alpine tundra ecosystems. *Arctic Science* 8, 572–608. https://doi.org/10.1139/as-2020-0058

In review

1. Criado et al (including AT and LH). (In revision). Plant traits poorly predict winner and loser shrub species in a warming tundra biome. *Nature Communications.*

Manuscripts in preparation

1. Davis, E., Trant, A., Hermanutz, L., and Way, R. (In preparation). Tundra drying and recent vegetation change in northern Nunatsiavut, Labrador. To be submitted to *Ecology*.
2. Forget et al. (In preparation). A machine learning approach to determine snow cover from ground surface temperature measurements. To be submitted to *Cold Regions Science and Technology*.
3. Forget et al. (In preparation). Influence of snow and vegetation on the ground thermal regime along a coastal gradient. To be submitted to the *Proceedings of the Twelfth International Conference on Permafrost.*
4. Johnson, A., Trant, A., Hermanutz, L., Davis, E., Siegwart Collier, L., Way, R., and Knight, T. (In preparation). Winter limits caribou (Tuttuk) forage availability. To be submitted to *Global Change Biology*.
5. Morin et al. (In preparation). Quantifying the role of internal climate variability in snow cover trends over northern Québec and Labrador. To be submitted to *Climate Dynamics*.
6. Mullally, S., Lauriault, P., and Trant, A. (In preparation). Ground vegetation response to shrubification in Pinware Hills, Labrador. To be submitted to *ARCTIC*.
7. Way et al. (In preparation). Machine learning based infilling of soil temperature observations to support permafrost modelling. To be submitted to the *Proceedings of the Twelfth International Conference on Permafrost.*

b) Conference presentations (poster, oral)

1. Colyn, V.*, Way, R., Wang, Y., Beer, J., Forget, A., Tutton, R., Lewkowicz, A. and Lapalme, C. (2022). Investigating the influences of microclimate and ecosystem properties on near surface permafrost conditions in Labrador, northeastern Canada. ArcticNet Annual Science Meeting 2022. Toronto, Ontario. Poster presentation.
2. Forget, A.*, Way, R.G. and Tutton, R. (2022). Using machine learning to estimate snow cover from ground temperature measurements. 2022 CMOS-CGU-ESC Joint Congress. Virtual Conference. Oral Presentation.
3. Forget, A.*, Way, R.G., Trant, A., Beer, J., Cuerrier, A., Davis, E., Hermanutz, L., Johnson, A., Lapalme, C., Le, N., Lightfoot, H., Laing, R., Larking, T., Lauriault, P., Lewkowicz, A., Mullally, S., Siegwart Collier, L., Saunders, M., Tutton, R., Wang, Y. and Whitaker, D. (2022). Understanding and predicting future climate-vegetation-cryosphere interactions in Nunatsiavut, Nunavik, Nitassinan, and NunatuKavut. Labrador Research Forum 2022. Virtual Conference. Oral Presentation.
4. Johnson, A., Trant, A.J. (2022). Impacts of climate warming on Caribou forage availability in the Torngat Mountains. Labrador Research Forum 2022. Virtual Conference. Oral Presentation.
5. Trant, A., Davis, E, Hermanutz, L, Beer, J., Cuerrier, A., Forget, A., Laing, R., Lapalme, C., Larking, T., Lauriault, P., Le, N., Lewkowicz, A., Lightfoot, H., Johnson, A., Mullully, S., Siegwart Collier, L., Tutton, R., Wang, Y., Whitaker, D., Way, R. (2022). Response of tundra plant communities to 13 years of experimental warming in Tongait KakKasuangita SilakKijapvinga (Torngat Mountains National Park). Labrador Research Forum 2022. Virtual Conference. Oral Presentation.
6. Lauriault, P.* and Trant, A.J. (2022). Abundance and quality of caribou forage along a latitudinal gradient in coastal Labrador. ArcticNet Annual Science Meeting 2022. Toronto, Ontario. Oral presentation.
7. Smitas-Kraas, M.*, Lauriault, P. and Trant, A.J. (2022). Shrubification in coastal Labrador and its microenvironmental changes to ground vegetation. ArcticNet Annual Science Meeting 2022. Toronto, Ontario. Poster presentation.
8. Way, R.G.*, Tutton, R., Wang, Y., Forget, A. and Beer, J. (2022). The response of Labrador's climate system to the extreme warm year of 2020-2021. Labrador Research Forum 2022. Virtual Conference. Oral Presentation.

9. Way, R.*, Trant, A., Leduc, M., Hermanutz, L., Siegwart Collier, L., Cuerrier, A., Laing, R., Whitaker, D., Zhang, Y., Beer, J., Colyn, V., Davis, E., Forget, A., Johnson, A., Lapalme, C., Larking, T., Lauriault, P., Le, N., Lewkowicz, A., Lightfoot, H., Mullally, S., Saunders, M., Smitas-Krass, M., Tutton, R. and Wang, Y. (2022). Understanding and predicting future climate-vegetation-cryosphere interactions in Nunatsiavut, Nunavik, and NunatuKavut. ArcticNet Annual Science Meeting 2022. Toronto, Ontario. Oral presentation.

c) Media interviews/attention

1. Interview with Dr. Robert Way. (2023). Gaps in weather forecasts pose health and safety risks for northern communities. *What On Earth with Laura Lynch*. CBC Podcast. https://www.cbc.ca/listen/live-radio/1-429-what-on-earth/clip/15964350-gaps-weather-forecasts-pose-health-safety-risks-northern
2. Video featuring team members Andrew Trant & Laura Siegwart Collier. (2022). Field Notes: The Future of Birds in a Changing Climate Field Notes. *Parks Canada Field Notes video series*. https://www.youtube.com/watch?v=YbxTKvvZxoE
3. Interview with Dr. Andrew Trant. (2022). Mountain biodiversity. *Future Ecologies* podcast (episode title: Mountain Legacies). https://www.futureecologies.net/listen/fe-4-9-mountain-legacies

d) Workshops

1. Attended Torngat Mountains Co-operative Management Board meeting. Hosted by Air Borealis, Parks Canada and the Nunatsiavut Government, Torngat Mountains Basecamp and Research Station, Saglek, Newfoundland and Labrador, Canada. August 2nd, 2022.
    a. Trant, A.* and Way, R.G.*. (2022). Changing tundra, permafrost, plants & people. Public lecture at Torngat Mountains Basecamp and Research Station. Saglek, Newfoundland and Labrador, Canada. Public presentation and consultation with the Torngat Mountains Co-operative Management Board. August 4th, 2022.

2. Resource Stewardship Workshop: Collaborative Approach for Sustainability. Hosted by the NunatuKavut Community Council, Happy Valley-Goose Bay, Newfoundland and Labrador, Canada. February 21-22, 2023.

e) Other knowledge mobilization activities (consultations, participation in senate/parliament hearings, podcasts, science briefs, etc.)

Digital resources (Infographics, Datasets, StoryMaps)

1. Two infographics were generated as posters and sent to the Torngat Basecamp in Summer 2022. Copies of these infographics were provided in English and Inuttitut.
2. A dataset describing Rock Glaciers in the Torngat Mountains has been published online at Nordicana D:
    a. Way, R.G., Wang,Y. 2022. Inventory of rock glaciers in the Torngat Mountains of northern Labrador, v. 1.0 (2021-2021). Nordicana D100, doi: 10.5885/45768XD-C1F53A9084E8494B.
3. An ArcGIS Online StoryMap is nearly complete and will summarize research undertaken in the Torngat Mountains National Park. A draft StoryMap is available at the link below but we are requesting that it not be shared until we have finalized the work: https://storymaps.arcgis.com/stories/2be6b8f50d4b4a7eb1ae540b3db02f9f

Consultations with partners, community representatives and organizations

1. Quarterly consultations with staff from the Nunatsiavut Government and Parks Canada;
2. Half-yearly consultations with staff from the Parc National Kuururjuaq (Kativik Regional Government) and the NunatuKavut Community Council;
3. Consultation with the Nunatsiavut Government and Stantec on permafrost and geomorphological conditions in the vicinity of the potential Nain Airstrip project site.
4. Specific scientific advice given to the Nunatsiavut Government's Archaeological Office, Environment and Lands Division, Policy Division and Infrastructure Division;
5. Specific scientific advice to the Western Newfoundland and Labrador Field Unit of Parks Canada;
6. Consultations with staff at the Nature Conservancy of Canada regarding permafrost in southern Labrador;
7. Consultations by RW with MHAs Lela Evans and Perry Trimper representing two provincial ridings in Labrador.
8. PL has been working with the NunatuKavut Community Council on lichen monitoring program development

9. Network Partners and networking added value

Describe partnerships with:
a) Inuit and northern communities and organizations; and,
b) Government agencies and industry within your research project over the last year.
c) Describe your National and International networking activities you have had during the last year, both within your ArcticNet project and with partners collaborating with your ArcticNet project. Indicate the value of the 'Networked Approach' and the ArcticNet Network for your research program.

a) Inuit and northern communities and organisations:

This project is a follow-up to two highly successful projects conducted in the region in partnership with entities working in northern science. One project was funded via a Nunatsiavut Government-Parks Canada-Weston Foundation partnership while the other was an ArcticNet research project led by our closest project collaborator Dr. Luise Hermanutz. Recognizing the need for maintaining and expanding research activities in coastal Labrador and Nunavik, we approached the Nunatsiavut Government, Kativik Regional Government, Parks Canada and the NunatuKavut Community Council about the ArcticNet open call and they supported our application for funds because it aligned with their respective research priorities related to climate change. We have continued to develop and maintain agreements, partnerships, permits and/or collaborations with the Nunatsiavut Government (NG) and the NunatuKavut Community Council (NCC) through our overarching research programs.

NG has continued to provide in-kind support for use of the accommodations and storage at the Nain Research Centre in Nain, Nunatsiavut during fieldwork activities in Summer 2022, Winter 2022 and the upcoming Winter 2023 field season. NG has also continued to provide logistical support for fieldwork at Nain including use of snowmobiles during our time in Nain. The project team has built a number of successful partnerships with NG for prior research work in Nunatsiavut and continues to work with Inuit and NG to ensure that research activities are conducted in a culturally respectful manner and to ensure that outcomes have meaningful benefits for Nunatsiavummiut. We are continuing to engage with the Torngat Mountains National Park Co-operative Management Board and in Summer 2022, our team presented to the Torngat Mountains National Park Co-operative Management Board on our research and engaged in a lengthy discussion session as to the future research priorities in the region. Other affiliated groups such as the Torngat Wildlife, Plants and Fisheries Secretariat have been engaged but to this point their priorities have not

focused on ecosystems to the same degree as our own so we have been unable to develop a full partnership in a meaningful way, yet.

NCC has been interested in our project since initially proposing the research and we have appreciated the ongoing support following their formal research processes. While we are interested in continuing to engage with NCC in discussions around this project, we are cognizant that the ongoing geopolitical situation in Labrador is making managing this relationship more challenging than expected. We are following our obligations in relation to the permitting process and will continue to respect the NCC's views on our research. To date, we have not been as successful at developing cohesive collaborations with the NCC like with NG. The distance of our research site at Pinware River Hills (PRH) from communities with high enrolment with NCC likely plays a role in these discussions. COVID-19 has also made it difficult for the types of in-person activities that often help to further build these relationships. Nevertheless, the project team members will be attending a Sustainability workshop hosted by NCC at the end of February and will likely be presenting on aspects of the ArcticNet program at that time.

b) Government agencies and industry within your research project:

Throughout this project we have maintained agreements, partnerships and collaborations with Parks Canada's Western and Labrador field unit (PC), the Kativik Regional Government (KRG), the Ouranos Consortium (OC) and Canada Centre for Remote Sensing (CCRS). PC continues to provide in-kind support for collecting data and supporting research activities at the Torngat Mountains Basecamp during research activities. The collaboration with PC builds on successful knowledge generation in northern Labrador between 2016-2018 through the Weston Foundation-Nunatsiavut Government - Parks Canada Award for research based out of Torngat Mountains Base Camp and Research Station. The partnership with PC focuses on maintaining monitoring apparatus within Torngat Mountains National Park for climatological, ecological and permafrost monitoring, but also has included data sharing in support of remote sensing analyses, climate modelling and permafrost modelling for TMNP. Although KRG committed to providing in-kind support for access to Parc national Kuururjuaq lands during adjacent fieldwork activities in TMNP, the COVID-19 pandemic has made that untenable at this point. However, team members assisted KRG staff in developing guidelines for establishing new monitoring apparatus within Parc national Kuururjuaq for climatological, ecological and permafrost monitoring. Consequently, KRG staff in August of 2020 established two sites in eastern Nunavik (Parc national Kuururjuaq) following these guidelines using the method developed by Tutton and Way (2021) from this ArcticNet project. We are also working

with KRG staff to provide training to KRG staff on field research techniques allowing monitoring to extend beyond the duration of this research project. Data from these stations were downloaded for the first time in Summer 2021 and have been provided to our research team through a data sharing agreement. Data downloaded in Summer 2022 were also recently provided to our team for analysis.

The Ouranos Consortium (OC) is a project partner for this research and has committed to providing logistical support for one project HQP so far through provision of computational resources, office space and access to the ClimEx ensemble. OC has also committed to supporting MLs second project HQP and has committed to providing similar support as in the case of the earlier HQP. OC, “Le plan d’action 2013-2020 sur les changements climatiques du gouvernement du Québec” and the non-profit organization MITACS also provided financial support to HQP (DM) activities at Université du Québec à Montréal for this project. Collaboration activities are also ongoing between this project and CCRS through the participation of project member Dr. Yu Zhang. Over the past three years, Dr. Zhang has contributed to the calibration, configuration and analysis of northern ecosystem soil temperature (NEST) (Zhang et al., 2003) model runs in support of permafrost modelling in coastal Labrador and Nunavik. Dr. Zhang also participated in the training of project HQP on using NEST for permafrost modelling and in conjunction with network investigators ensured two HQP (RT & AF) were able to generate the necessary remote sensing, field and climate inputs to run NEST (see Tutton et al., 2021; Forget et al. In preparation).

c) National and international networking activities:

Contributions from this project’s research activities continue to be added to international databases such as the High Latitude Drone Ecology network, the International Tundra Experiments and the SoilTemp global soil temperature database. Each of these are large international research projects that span multiple institutions. Data collected in Torngat Mountains National Park has already been contributed to all three international projects and will continue to do so in the future. Data from PRH and NBH will be contributed to the SoilTemp database at this project’s conclusion. Data collected at our ArcticNet supported long term tundra monitoring sites in Nakvak Brook, TMNP, are being used in a synthesis analysis on which tundra plant species will benefit the most/least with continued climate warming (Criado et al., in revision). Our research contributions to the SoilTemp initiative (Lambrechts et al. 2022) and a recent review of snow-ecology interactions under climate change also show our commitment to international collaboration using insights gained from this research project (Rixen et al. 2022).

Finally, in the absence of ArcticNet’s support for our current project many of the data series that we have continued in TMNP would have effectively ended in 2017.

ArcticNet's networked approach has served this project well by allowing us to develop an interdisciplinary team of researchers that can work together following a common research theme. ArcticNet's credible position as an organization committed to the furthering of northern science and its commitment to enhancing northern and Indigenous participation has benefited our science and ability to build partnerships. We continue to be committed to the work that ArcticNet is doing towards integration of northern perspectives into research and are indebted to ArcticNet for our supporting our project in working towards those goals. As these research projects move into their next phases, we are learning lessons about how to best leverage our existing networks and hope to build on the opportunities the ArcticNet support has given us to work in the North.

10. Metadata and DATA

Please provide a brief overview of your Data Management Plan below [250 words maximum], including access, storage, ownership, security, confidentiality and privacy. Insert inks to metadata and data repositories. Please refer to the ArcticNet Data Management Policy.
Link to guide: https://portagenetwork.ca/wp-content/uploads/2020/04/BriefGuide_Portage_EffectiveDMP.pdf
Link to Portage Network's DMP Assistant: https://assistant.portagenetwork.ca/en

- ***Note that this section have been pre-filled with text from your prior report, please review, correct, and complete any missing information.***

Our overall data management, data sharing and dissemination plan has been developed following consultations with the Nunatsiavut Government, the NunatuKavut Community Council, Parks Canada and the Kativik Regional Government. Our project is committed to a free and open provision of research data to the public, where permitted by partners. Every single peer reviewed journal publication from this project has been published with full open access to the public and we have demonstrated a commitment to supporting open access to data and code to support the broader community. All research future publications will be published in open access peer reviewed journals to ensure access to community members throughout the IRIS regions.

Our current data management plan (revised in 2020) is to publish our data and metadata online in repositories during fall of 2023 and then update these resources again after the winter 2024 field season. Data formats will be comma space delimited, GeoTIFF, shapefile and/or excel files. Specific data products that will be published in open access repositories will include logger data collected at monitoring stations (including ground surface temperature data), gridded climate and vegetation data products (shapefiles or .geotiffs), and ground photographs of biodiversity plots. We will

also publish full coordinates of research locations to ensure accurate revisitation. Repositories will include Nordicana D, SoilTemp and the Global Terrestrial Permafrost Network. Back-ups of research data will also be stored on external hard drives situated at network investigator home universities (Queen's University, University of Waterloo & Universite de Quebec a Montreal).

11. Caption List for Tables and Figures

If you have used figures or tables in the sections above, please provide the original formats in high resolution for publication purposes, in a separate file or files using one of the following formats: .pdf, .jpg, .png, .tiff, .xlxs, .ppt

N/A

12. Information on Researchers, HQP, NCE budget and non-NCE contributions

Please complete all information on Researchers and HQP on the Excel Spreadsheet, note that the spreadsheet contains several tabs. Please fill all the cells.

- ***Note that the Appendix have been pre-filled with data from your prior report, please review, correct, and complete any missing information.***

Please see completed worksheets.