



Natural Resources
Canada

Ressources naturelles
Canada

**GEOLOGICAL SURVEY OF CANADA
OPEN FILE 9299e**

**Field observations of climate, soil, and ecological
conditions within the first five years following wildfire,
southern Northwest Territories**

**J.E. Holloway, Y. Wang, A.G. Lewkowicz, S.A. Wolfe,
M.R. Turetsky, and J.L. Baltzer**

2025

Canada 

**GEOLOGICAL SURVEY OF CANADA
OPEN FILE 9299e**

**Field observations of climate, soil, and ecological conditions
within the first five years following wildfire, southern
Northwest Territories**

**J.E. Holloway¹, Y. Wang², A.G. Lewkowicz¹, S.A. Wolfe², M.R. Turetsky³, and
J.L. Baltzer⁴**

¹Department of Geography, Environment and Geomatics, University of Ottawa, 60 University,
Ottawa, Ontario K1N6N5

²Natural Resources Canada, 601 Booth Street, Geological Survey of Canada, Ottawa, Ontario K1A E08

³Renewable and Sustainable Energy Institute, Department of Ecology and Evolutionary Biology, University of
Colorado Boulder, Boulder, CO, 80309-0552, USA

⁴Biology Department, Wilfrid Laurier University, 75 University Avenue West, Waterloo, Ontario N2L 3C5

2025

© His Majesty the King in Right of Canada, as represented by the Minister of Natural Resources, 2025

Information contained in this publication or product may be reproduced, in part or in whole, and by any means, for
personal or public non-commercial purposes, without charge or further permission, unless otherwise specified.

You are asked to:

- exercise due diligence in ensuring the accuracy of the materials reproduced;
- indicate the complete title of the materials reproduced, and the name of the author organization; and
- indicate that the reproduction is a copy of an official work that is published by Natural Resources Canada (NRCan)
and that the reproduction has not been produced in affiliation with, or with the endorsement of, NRCan.

Commercial reproduction and distribution is prohibited except with written permission from NRCan. For more
information, contact NRCan at copyright-droitdauteur@nrcan-rncan.gc.ca.

This publication is available for free download through the NRCan Open Science and Technology Repository
(<https://ostrnrcan-dostrncan.canada.ca/>).

Recommended citation

Holloway, J.E., Wang, Y., Lewkowicz, A.G., Wolfe, S.A., Turetsky, M.R., and Baltzer, J.L., 2025. Field observations
of climate, soil, and ecological conditions within the first five years following wildfire, southern Northwest
Territories; Geological Survey of Canada, Open File 9299e, 1 .zip file. <https://doi.org/10.4095/pzyenpg5r0>

Publications in this series have not been edited; they are released as submitted by the author.

ISSN 2816-7155
ISBN 978-0-660-78565-3
Catalogue No. M183-2/9299E-PDF
<https://doi.org/10.4095/pzyenpg5r0>

Introduction

This Open File contains field measurements and data for the characterization of climate, permafrost, and ecological conditions at 19 study sites in the southern Northwest Territories, northeast of Great Slave Lake. Of the 19 study sites, 16 were disturbed by forest fire in 2014 or 2015 (burned - B), while three sites remained undisturbed/unburned (unburned - UB). Summary data and metrics are presented in the main document, and daily mean air, ground surface, and ground temperatures are provided as .csv files. This Open File supports ongoing research by the Geological Survey of Canada on post-fire permafrost dynamics in the Northwest Territories and accompanies Open File 9298, entitled “Electrical resistivity tomography surveys for characterizing permafrost conditions following wildfire, southern Northwest Territories, 2015-2018”. Additional details are available in Holloway (2020).

This Open File contains a .zip of the following files:

- 1) B1.csv – daily mean ground surface and ground temperatures at B1
- 2) B2.csv – daily mean air, ground surface, and ground temperatures at B2
- 3) B3.csv – daily mean air, ground surface, and ground temperatures at B3
- 4) B4.csv – daily mean ground surface temperatures at B4
- 5) B5.csv – daily mean ground surface and ground temperatures at B5
- 6) B6.csv – daily mean air, ground surface, and ground temperatures at B6
- 7) B7.csv – daily mean ground surface and ground temperatures at B7
- 8) B8.csv – daily mean air, ground surface, and ground temperatures at B8
- 9) B9.csv – daily mean ground surface and ground temperatures at B9
- 10) B10.csv – daily mean ground surface and ground temperatures at B10
- 11) B11.csv – daily mean ground surface temperatures at B11
- 12) B12.csv – daily mean air, ground surface, and ground temperatures at B12
- 13) B13.csv – daily mean ground surface and ground temperatures at B13
- 14) B14.csv – daily mean ground surface and ground temperatures at B14
- 15) B15.csv – daily mean ground surface and ground temperatures at B15
- 16) B16.csv – daily mean ground surface and ground temperatures at B16
- 17) UB1.csv – daily mean ground surface and ground temperatures at UB1
- 18) UB2.csv – daily mean ground surface and ground temperatures at UB2
- 19) UB3.csv – daily mean air, ground surface, and ground temperatures at UB3

Study area and sites

The following description of the study area and study sites is also provided in Open File 9298, entitled “Electrical resistivity tomography surveys for characterizing permafrost conditions following wildfire, southern Northwest Territories, 2015-2018”.

The monitoring sites were selected by applying a stratified random sampling scheme within seven areas burned by wildfire in 2014 or 2015 along Highways 1 and 3, mainly between Kakisa and Behchoko (Figure 1). The strata represented a range of vegetation types, fire severities, and fire histories. Further site selection occurred in the field, based on the presence of a frost table and other conditions indicative of permafrost. The sites were established in 2015 (n=16), 2016 (n=2), and 2017 (n=1) and were revisited annually from 2015 to 2019, with some exceptions due to logistical constraints (Table 1). The study sites are aligned along a transect that runs southwest to northeast, perpendicular to regional mean annual air temperature isotherms, the boundary between the sporadic and extensive discontinuous permafrost zones (Heginbottom et al. 1995), and the boundary between the Taiga Plains and Taiga Shield ecozones.

The regional climate is subarctic and continental, with a mean annual air temperature (MAAT) of -4.0°C at Yellowknife (62.5°N) and -2.2°C at Hay River (60.1°N) (1991-2020 climate normal) (Environment and Climate Change Canada 2025). Mean total annual precipitation is 294 mm at Yellowknife and 320 mm at Hay River, with snow fractions of 0.39 and 0.34, respectively (1991-2020 climate normal) (Environment and Climate Change Canada 2025).

Fifteen sites are in the Taiga Plains ecozone, while four sites near Yellowknife are in the Taiga Shield ecozone. The Taiga Plains consist of a gently rolling sedimentary bedrock plain overlain by till and glaciolacustrine deposits. The vegetation is predominantly black spruce (*Picea mariana*) in the lowlands and mixed forest in the uplands, with understories commonly composed of mosses, lichens, sedges, and Labrador tea (*Rhododendron groenlandicum*). The Taiga Shield comprises undulating exposed igneous and metamorphic bedrock, with low-lying wetlands underlain by till and glaciolacustrine deposits. Jack pine (*Pinus banksiana*), black spruce, and paper birch (*Betula papyrifera*) occur in thin soils at upland sites, while black spruce dominates lowlands. Wetlands constitute 40% of the area, with peat thicknesses of 2 to 6 m (Gibson et al. 2018).

The southern part of the transect falls within the sporadic discontinuous permafrost zone, where permafrost thicknesses are less than 30 m and mean annual ground temperatures are greater than -1°C (Smith et al. 2008, 2015). The northern part of the transect is in the extensive discontinuous permafrost zone, where permafrost is less than 50 m thick and has mean annual ground temperatures above -2°C (Wolfe et al. 2015, Morse et al. 2016).

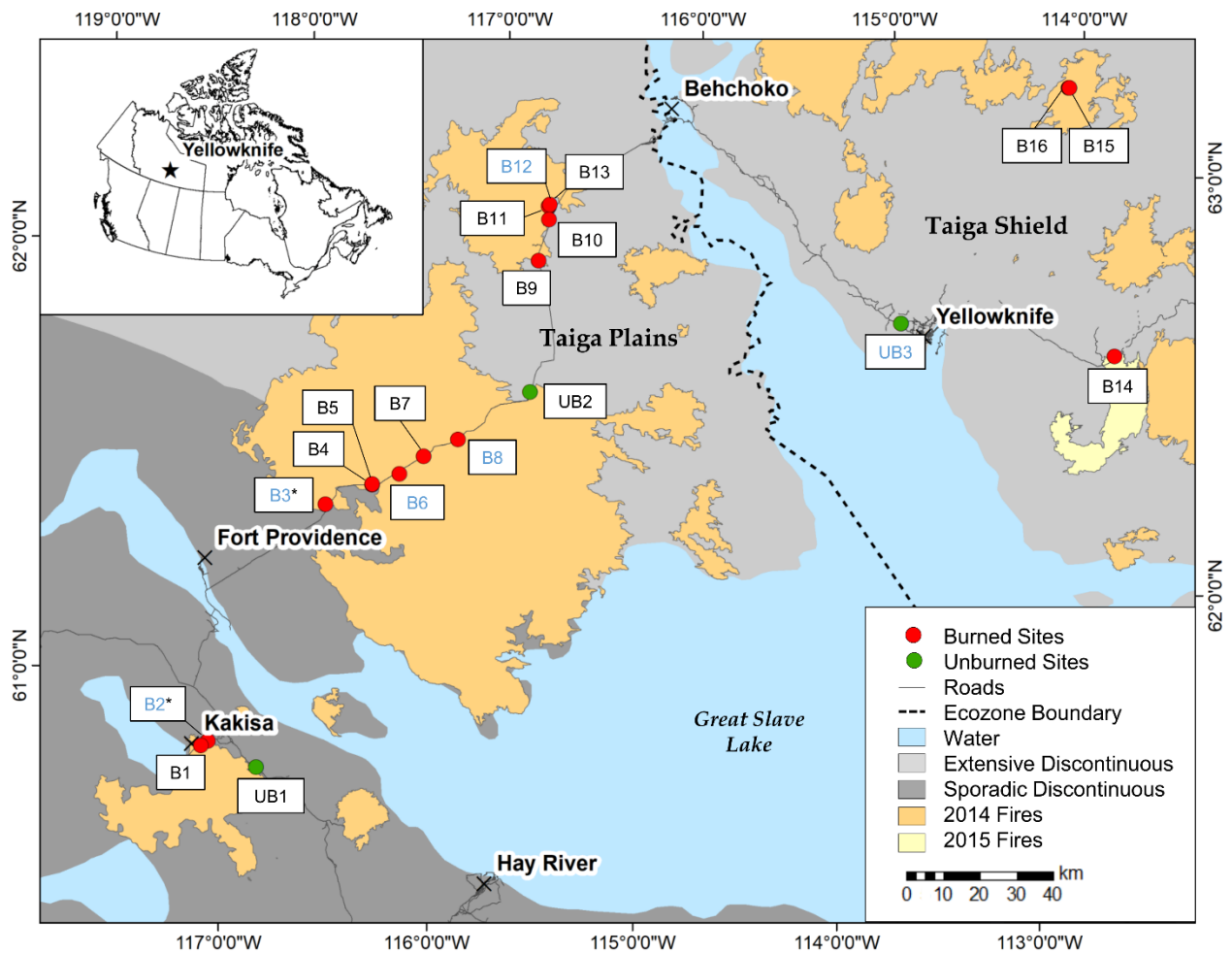


Figure 1. Map of study area in the southern Northwest Territories, Canada, including burned (n=16) and unburned (n=3) sites, major roads, 2014 and 2015 fire boundaries (Northwest Territories Centre for Geomatics 2015), ecozones (Government of Northwest Territories 2008), and permafrost distribution zones (Heginbottom et al. 1995). The sites marked with an asterisk (*) had no permafrost present when first established and sites labelled in blue include air temperature stations. Inset map shows the location of Yellowknife within Canada.

Table 1. Study site names, coordinates, descriptions, ecozones, dates visited, and estimated permafrost thicknesses.

Site name / ID	Latitude, Longitude (°)	Description (e.g., soil moisture, landform, vegetation, local topography)	Ecozone	Dates visited (YYYY-MM-DD)	Permafrost thickness (m)
B1 (SS33-9a)	60.941, -117.366	Mesic-subhygric. Peat plateau, lots of thermokarst. No slope.	South Taiga Plains	2015-06-16 2015-08-16 2016-05-17 2016-09-01 2017-08-29 2018-09-03	15-20
B2 (SS33-6c)	60.958, -117.339	Subhygric. Spruce forest, lots of mounding. No slope.	South Taiga Plains	2015-06-04 2015-08-14 2016-09-06	None
B3 (ZF20-34b)	61.608, -117.154	Mesic-subxeric. Gradient from pine to spruce to bog. No slope.	Central Taiga Plains	2015-06-02 2015-08-15	None
B4 (ZF20-6b-1)	61.689, -116.952	Mesic-subxeric. Severely burned, all trees down. No slope.	Central Taiga Plains	2015-06-08 2015-08-15 2016-05-13 2016-09-07 2017-09-01 2018-09-07	10 (patch)
B5 (ZF20-6b-LK)	61.692, -116.953	Mesic-subhygric. Wet spruce forest near pond; one end has thick peat plateau and the other is a very wet marsh.	Central Taiga Plains	2015-06-11 2015-08-18 2016-05-13 2016-09-05 2017-09-02 2018-09-06	15
B6 (ZF20-12b)	61.736, -116.834	Mesic. Gradient from pine to black spruce to bog. No slope.	Central Taiga Plains	2015-06-14 2015-08-13 2016-05-15 2016-09-03 2017-08-31 2018-09-08	5 (small patch)
B7 (ZF20-9c)	61.796, -116.740	Mesic-subhygric. Spruce forest with lots of mounds, and small section of unburned. No slope.	Central Taiga Plains	2015-06-10 2015-08-19 2016-05-14 2016-09-04 2017-09-01 2018-09-05	5-10
B8 (ZF20-4a)	61.863, -116.597	Mesic-subxeric. Gradient of burn severity from unburned to severely burned. No slope.	Central Taiga Plains	2015-06-02 2015-08-17 2016-05-14 2016-09-02 2017-08-30 2018-09-09	10-20
B9 (ZF46-18b)	62.345, -116.482	Mesic-subhygric. Pine with small area of black spruce. No slope.	North Taiga Plains	2015-06-09 2015-08-12 2016-05-11 2016-09-14 2017-09-05 2018-09-12	>5
B10 (ZF46-35c)	62.450, -116.496	Mesic. Pine and dwarf black spruce patch. No slope.	North Taiga Plains	2015-06-09 2015-08-20 2016-05-16 2016-09-13 2017-09-05 2018-09-12	>5
B11 (ZF46-1b-1)	62.480, -116.518	Mesic-subhygric. Small valley, pine on top of hill, spruce in valley bottom (wet/boggy). Hill slope is 30° and valley bottom (60 m) is flat. Sandy.	North Taiga Plains	2015-06-06 2015-08-20 2016-05-15 2017-09-06 2018-09-11	5 (small patch)
B12 (ZF46-1b-2)	62.481, -116.520	Mesic-subhygric. Small valley, pine on top of hill, spruce in valley bottom (wet/boggy). Transect goes	North Taiga Plains	2015-06-06 2015-08-20 2016-05-20 2016-09-15	5-10

		through burned and unburned area. Hill slope is 30° and valley bottom (60m) is flat. Sandy.		2017-09-06 2018-09-11	
B13 (ZF46-1c)	62.485, -116.518	Mesic. Spruce stand. Sandy. No slope.	North Taiga Plains	2015-06-10 2015-08-19 2016-06-03 2016-09-15 2017-09-05 2018-09-10	5-10
B14 (TIB-1)	62.522, -113.382	Burned peatland with ice wedges.	Taiga Shield	2016-06-16 2016-09-12 2017-09-07 2018-09-14	>24
B15 (LL-PEAT)	63.133, -114.004	Peatland in valley next to lithalsas.	Taiga Shield	2015-06-18 2015-08-30 2016-09-10 2018-08-25	>24
B16 (LL-LITH2)	63.132, -114.006	Lithalsa topped with spruce and birch trees.	Taiga Shield	2015-06-18 2015-08-30 2016-09-11 2018-08-25	>24
UB1 (KAK-UB)	60.935, -117.072	Mesic-subhygric. Unburned forest. No slope.	South Taiga Plains	2017-08-23 2018-09-04	5
UB2 (HWY3-UB-1A)	62.029, -116.314	Mesic-subhygric. Unburned forest. No slope.	Central Taiga Plains	2016-05-18 2016-09-09 2017-09-03 2018-09-10	>24
UB3 (UB-1)	62.458, -114.532	Unburned peatland.	Taiga Shield	2015-06-07 2015-08-11 2016-05-31 2016-09-16 2017-09-07 2018-09-13	>24

Overview of data

Data consists of direct and derived field measurements for the characterization of climate, soil, and ecological conditions at the 19 study sites (Table 2).

Meteorological and ground temperature conditions are summarized based on sub-daily temperatures recorded at the study sites in the air, at the ground surface, and in the ground. Daily mean air, ground surface, and ground temperatures are provided in the .csv files for all study sites. Soil conditions are summarized at some sites from cores that were collected by drilling. Reported soil conditions include excess ice content, gravimetric moisture content, bulk density, grain size, and organic matter content. Ecological conditions in relation to burn severity and residual organic layer thickness are reported for the 16 burned sites.

Table 2. Summary of direct and derived field measurements made at 16 burned and three unburned study sites in the southern Northwest Territories from 2015 to 2019.

Variable	Measurement method or instrument; Calculation or derivation method	Measurement frequency, parameters, reference	Measurement accuracy, precision, error
Direct climatic/meteorological measurements			
Air temperature	HOBO Pro U23-003	Frequency: 2 hours	Accuracy $\pm 0.21^{\circ}\text{C}$, Precision $\pm 0.02^{\circ}\text{C}$
Ground surface temperature	DS1922L Thermochron iButton	Frequency: 4 hours	Accuracy $\pm 0.5^{\circ}\text{C}$, Precision $\pm 0.0625^{\circ}\text{C}$
Ground temperature	HOBO Pro U12-008	Frequency: 2 hours	Accuracy $\pm 0.25^{\circ}\text{C}$, Precision $\pm 0.03^{\circ}\text{C}$
Snow depth	DS1921G-F5 Thermochron iButton	Frequency: 4 hours	Accuracy $\pm 1^{\circ}\text{C}$, Precision $\pm 0.5^{\circ}\text{C}$
Derived climatic/meteorological measurements			
Annual mean air temperature (AMAT)	Mean of daily air temperature	Hydrological year: September 1-August 31	-
Annual mean ground surface temperature (AMGST)	Mean of daily ground surface temperature	Hydrological year: September 1-August 31	-
Annual mean ground temperature (AMGT) at 1 m	Mean of ground temperature at 1 m	Hydrological year: September 1-August 31	-
Freezing degree days (air) (FDDa)	Sum of daily air temperatures below 0°C	Freezing season: October 1-April 30	-
Thawing degree days (air) (TDDa)	Sum of daily air temperatures above 0°C	Thawing season: May 1-September 30	-
Freezing degree days (ground surface) (FDDs)	Sum of daily ground surface temperatures below 0°C	Freezing season: October 1-April 30	-
Thawing degree days (ground surface) (TDDs)	Sum of daily ground surface temperatures above 0°C	Thawing season: May 1-September 30	-
Freezing n-factor (n_F)	Ratio of freezing degree days in the air and at the ground surface	Freezing season: October 1-April 30	-
Thawing n-factor (n_T)	Ratio of thawing degree days in the air and at the ground surface	Thawing season: May 1-September 30	-
Surface offset (SO)	AMGST-AMAT	Hydrological year: September 1-August 31	-
Nival offset (NO)	AMGST(F)-AMAT(F)	Freezing season: October 1-April 30	-
Thermal offset (TO)	TTOP-AMGST	Hydrological year: September 1-August 31	-
Maximum snow cover depth	Interpreted from iButton stake	Lewkiewicz (2008)	Error: 10-20 cm
Snow depth days (SDD)	Sum of snow depth days	-	-
Soil characteristics			
Excess ice content (EIC)	Volumetric proportion of ice present that exceeds the pore volume of thawed sample	Kokelj and Burn (2003)	-
Bulk density (bD)	Dry density	-	-
Gravimetric moisture content (GMC)	Amount of water present relative to dry sample mass	van Everdingen (2005)	-
Mean grain size	Microtrac S3500 laser particle size analyzer	-	-
Grain size distribution	Microtrac S3500 laser particle size analyzer	-	-
Organic matter content	LECO thermo-gravimetric analyzer with integrated balance, TGA701; Loss on ignition	Heiri et al. (2001)	-
Direct environmental characteristics			
Height of adventitious roots (ARH)	Mean of three measurements	Measured along linear transects	-
Residual organic layer thickness	Soil pits	-	-
Derived environmental characteristics			
Depth of burn	Calculation using height of adventitious roots and residual organic layer thickness	Walker et al. (2018)	-
Pre-fire organic layer thickness	Sum of residual organic layer thickness and depth of burn	-	-
Proportion of organic layer lost	Proportion of depth of burn to pre-fire organic layer thickness	-	-

Climatic/meteorological conditions

Air temperature

Air temperatures were measured at six sites (B2, B3, B6, B8, B12, UB3) within radiation shields installed at heights of 1.5 m using Hobo Pro U23-003 loggers. Each of these sites represents air temperatures for a cluster of nearby sites, located within a maximum radius of 20 km. Air temperature data were aggregated from bihourly measurements to daily maximum, minimum, and mean values using a custom R script (Way et al. 2018). Air temperatures for sites without stations were estimated using a weighted average, based on linear distances with the two nearest stations. For site B14, there was no site within 20 km to use for a weighted average, so the air temperature from site UB3 (60 km away) was used. Values at B14 and UB3 were expected to be similar as they are at the same latitude. Between-site regression analyses had an $r^2 > 0.94$, indicating that air temperatures are regionally, rather than locally, controlled. Aggregated and infilled air temperatures were used to calculate annual mean air temperatures (AMAT), surface offsets (SO), nival offsets (NO), and freezing and thawing degree days (FDD_a, TDD_a).

Ground surface temperature

Ground surface temperatures were measured with DS1922L Thermochron iButton temperature loggers installed at a depth of 5 cm at each site (Table 2). A second set of temperatures was recorded in unburned ground at each of the seven sites where such areas existed. Ground surface temperatures were aggregated from sub-daily measurements (taken every 4 hours) to daily maximum, minimum, and mean values using a custom R script (Way et al. 2018). Ground surface temperatures were infilled using the relation with the air temperature at that site, where the relation had an $r^2 > 0.8$. Aggregated and infilled ground surface temperatures were used to calculate annual mean ground surface temperatures (AMGST), surface offsets (SO), nival offsets (NO), thermal offsets (TO), and the number of freezing and thawing degree days at the ground surface (FDD_s, TDD_s).

Ground temperature

Ground temperatures were measured using Hobo Pro U12-008 loggers with four external thermistors (accuracy $\pm 0.25^\circ\text{C}$; precision $\pm 0.03^\circ\text{C}$). Thermistors were installed at the frost table at the time of instrumentation and at several depths within the active layer at all sites and, where possible, within plastic casing installed in boreholes drilled into the permafrost using the water jet technique. Bi-hourly ground temperature measurements were aggregated to daily maximum, minimum, and mean values using a custom R script (Way et al. 2018). Gaps in the ground temperature record were infilled using a cubic spline interpolation (Riseborough and Burgess 1996). For gaps smaller than 10 days, the 10-day period on either side of the missing data was used to generate the relationship. For gaps larger than 10 days, a 30-day period on either side was used. To infill gaps at the beginning of the ground temperature record, a linear relationship was generated from the 20 days following the missing data. Aggregated and infilled ground temperatures were used to calculate annual mean ground temperatures (AMGT) at ~ 1 m depth and thermal offsets (TO).

Table 3. Depths of temperature loggers installed at study sites. The sensor depth used to calculate AMGT at ~1.0 m is shown in bold. GST corresponds to ground surface temperature.

Site	Instrumentation
B1	Burned: GST, 0.2, 0.4, 0.6, 0.8 , 1.0, 1.5, 2.5, 3.1 m Unburned: GST, 0.1, 0.3, 0.5, 0.7 , 1.0, 1.5, 2.0, 2.4 m
B2	Burned: GST, 0.15, 0.4, 0.5, 0.7, 0.9 m Unburned: GST, 0.15, 0.5, 0.7, 0.9 m
B3	Burned: GST, 0.25, 0.5, 0.75, 1.0 m Unburned: GST, 0.25, 0.5, 0.75, 1.0 m
B4	Burned: GST
B5	Burned: GST, 0.5, 0.75, 1.0 , 1.5, 2.0, 2.5 m
B6	Burned: GST, 0.15, 0.3, 0.45, 0.5, 0.6 m
B7	Burned: GST, 0.2, 0.4, 0.6, 0.8 m Unburned: GST, 0.2, 0.4, 0.8 m
B8	Burned: GST, 0.2, 0.4, 0.5, 0.6, 0.8 m Unburned: GST, 0.2, 0.4, 0.6, 0.8 m
B9	Burned: GST, 0.15, 0.3, 0.45 , 0.6 m
B10	Burned: GST, 0.2, 0.4, 0.8 m
B11	Burned: GST
B12	Burned: GST, 0.25, 0.5, 1.0 , 1.5, 1.9 m Unburned: GST, 0.5, 0.75, 1.0 , 1.5 m
B13	Burned: GST, 0.2, 0.4, 0.6, 0.8 m Unburned: GST, 0.1, 0.2, 0.4, 0.6 m
B14	Burned: GST, 0.2, 0.5, 1.0 m
B15	Burned: GST, 0.75 , 1.5, 2.2 m
B16	Burned: GST, 0.75, 1.0 , 1.5, 2.0, 2.2, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0 m
UB1	Unburned: GST, 0.15, 0.35, 0.45, 0.55 m
UB2	Unburned: GST, 0.25, 0.5, 1.0 , 1.5 m
UB3	Unburned: GST, 0.5, 1.0 , 1.5, 2.0, 3.0, 4.0, 6.0, 7.4 m

Summary metrics

Annual freezing and thawing degree-day (FDD and TDD) totals were calculated for the air (FDD_a and TDD_a) and ground surface (FDD_s and TDD_s) from the temperature records by summing daily mean temperatures below and above 0°C, respectively (Table 4). For this calculation, the freezing season was assumed to be October 1 to April 30, and the thawing season was assumed to be May 1 to September 30 (Smith et al. 2015).

Freezing and thawing n-factors were calculated using the following equations (Klene et al. 2001, Karunaratne and Burn 2004):

$$n_F = \frac{FDD_s}{FDD_a}; n_T = \frac{TDD_s}{TDD_a}$$

where n_F is the freezing n-factor, FDD_s is the surface freezing degree-day total, and FDD_a is the air freezing degree-day total, and n_T is the thawing n-factor, TDD_s is the surface thawing degree-day total, and TDD_a is the air thawing degree-day total (Table 4).

Surface (SO), nival (NO), and thermal offsets (TO) were calculated using the following equations:

$$\begin{aligned} SO &= AMGST - AMAT \\ NO &= AMGST_F - AMAT_F \\ TO &= TTOP - AMGST \end{aligned}$$

where AMGST_F and AMAT_F are the mean ground surface and mean air temperatures measured during the freezing season, and TTOP is the annual mean temperature at the top of permafrost (represented by the AMGT at 1 m depth) (Smith and Riseborough 2002) (Table 5).

Snow depth and duration

Snow cover depth and duration were assessed at each site from temperature data collected using vertically arranged DS1921G-F5 Thermochron iButton temperature loggers fixed to a wooden stake (typically at heights of 10, 20, 30, 40, 50, 60, and 80 cm) (Lewkowicz 2008) (Table 6). iButtons covered by snow experience smaller diurnal temperature variations than those exposed in the air above (Lewkowicz 2008). Snow depths were inferred using the absolute differences between the 2-day future running mean and the standard deviation between the highest iButton (typically 80 cm) and all other heights on the stake. Snow was deemed to be present at a certain height if:

- the temperature recorded was below a temperature threshold of 1°C;
- the maximum temperature recorded in the subsequent 24 hours was below the temperature threshold of 1°C;
- the difference in 2-day future running means was below the temperature threshold of 1°C; and,
- the difference in the 2-day standard deviation was below a threshold of 1°C.

If snow was present at one height, and not at the height above, snow depth was assumed to be mid-way between the iButtons. Given the vertical spacing of the iButtons, the accuracy of snow depth is ± 5 or 10 cm. Daily snow depths were used to derive maximum snow depth and snow-depth days (SDD).

Table 4. Annual freezing and thawing degree days for the air and ground surface and freezing (n_F) and thawing (n_T) n-factors at burned and unburned areas of the study sites, if applicable. Values of n_F are for freezing seasons that ended in the calendar year listed. Dashes indicate that no data are available.

Site	Year	FDD _a	TDD _a	FDD _s (B)	TDD _s (B)	n_F (B)	n_T (B)	FDD _s (UB)	TDD _s (UB)	n_F (UB)	n_T (UB)
B1	2016	2432	2075	83	1583	0.03	0.76	139	1712	0.06	0.83
	2017	2537	2136	207	1086	0.08	0.51	326	1482	0.13	0.69
	2018	2935	1789	111	1456	0.04	0.81	21	985	0.01	0.55
	2019	2414	-	51	-	0.02	-	156	-	0.06	-
B2	2016	2432	2075	-	-	-	-	-	-	-	-
	2017	2537	2136	-	-	-	-	-	-	-	-
	2018	2935	1789	-	-	-	-	-	-	-	-
	2019	2550	-	-	-	-	-	-	-	-	-
B3	2016	2491	2089	-	-	-	-	-	-	-	-
	2017	2748	2167	-	-	-	-	-	-	-	-
	2018	3045	1798	-	-	-	-	-	-	-	-
	2019	2654	-	-	-	-	-	-	-	-	-
B4	2016	2501	2092	356	1656	0.14	0.79	-	-	-	-
	2017	2743	2169	663	1842	0.24	0.85	-	-	-	-
	2018	3018	1781	689	1508	0.23	0.85	-	-	-	-
	2019	2688	-	553	-	0.21	-	-	-	-	-
B5	2016	2501	2092	320	1346	0.13	0.64	-	-	-	-
	2017	2743	2169	550	1571	0.20	0.72	-	-	-	-
	2018	3018	1781	308	1685	0.10	0.95	-	-	-	-
	2019	2598	-	184	-	0.07	-	-	-	-	-
B6	2016	2506	2094	225	1569	0.09	0.75	-	-	-	-
	2017	2740	2171	590	1633	0.22	0.75	-	-	-	-
	2018	3003	1772	349	1563	0.12	0.88	-	-	-	-
	2019	2709	-	221	-	0.08	-	-	-	-	-
B7	2016	2533	2069	131	1886	0.05	0.91	98	1274	0.04	0.62
	2017	2784	2142	270	1750	0.10	0.82	214	1343	0.08	0.63
	2018	3050	1745	211	1586	0.07	0.91	88	1502	0.03	0.86
	2019	2734	-	237	-	0.09	-	91	-	0.03	-
B8	2016	2567	2038	310	1831	0.12	0.90	357	1297	0.14	0.64
	2017	2840	2105	277	1608	0.10	0.76	326	1221	0.11	0.58
	2018	3110	1709	391	1581	0.13	0.93	422	1081	0.14	0.63
	2019	2699	-	210	-	0.08	-	290	-	0.12	-
B9	2016	2799	1940	109	1153	0.04	0.59	-	-	-	-
	2017	3072	2006	236	997	0.08	0.50	-	-	-	-
	2018	3312	1617	304	933	0.09	0.58	-	-	-	-
	2019	2956	-	171	-	0.06	-	-	-	-	-
B10	2016	2850	1919	195	1853	0.07	0.97	-	-	-	-
	2017	3123	1985	152	1769	0.05	0.89	-	-	-	-
	2018	3357	1598	334	1541	0.10	0.96	-	-	-	-
	2019	3042	-	-	-	-	-	-	-	-	-
B11	2016	2866	1912	99	1508	0.03	0.79	-	-	-	-
	2017	3139	1979	86	1702	0.03	0.86	-	-	-	-
	2018	3371	1591	113	1564	0.03	0.98	-	-	-	-
	2019	3057	-	-	-	-	-	-	-	-	-
B12	2016	2866	1912	475	1175	0.17	0.61	403	1431	0.14	0.75
	2017	3139	1979	463	1154	0.15	0.58	351	1561	0.11	0.79
	2018	3371	1591	724	855	0.21	0.54	411	1287	0.12	0.81
	2019	3028	-	411	-	0.14	-	210	-	0.07	-
B13	2016	2866	1912	-	-	-	-	-	-	-	-
	2017	3139	1979	108	1515	0.03	0.77	122	1161	0.04	0.59
	2018	3371	1591	101	1436	0.03	0.90	125	1171	0.04	0.74
	2019	3028	-	59	-	0.02	-	58	-	0.02	-
B14	2016	-	-	-	-	-	-	-	-	-	-
	2017	3000	2053	426	1521	0.14	0.74	-	-	-	-
	2018	3281	1622	843	1049	0.26	0.65	-	-	-	-
	2019	3026	-	-	-	-	-	-	-	-	-
B15	2016	3216	1958	1175	1786	0.37	0.91	-	-	-	-
	2017	3331	2033	1454	1748	0.44	0.86	-	-	-	-
	2018	3596	1560	1734	1419	0.48	0.91	-	-	-	-
	2019	3396	-	1395	-	0.41	-	-	-	-	-

B16	2016	3216	1958	1396	1460	0.43	0.75	-	-	-	-
	2017	3331	2033	1390	1489	0.42	0.73	-	-	-	-
	2018	3596	1560	2032	1171	0.56	0.75	-	-	-	-
	2019	3396	-	1930	-	0.57	-	-	-	-	-
UB1	2016	-	-	-	-	-	-	-	-	-	-
	2017	-	-	-	-	-	-	-	-	-	-
	2018	2920	1774	-	-	-	-	713	989	0.24	0.56
	2019	2532	-	-	-	-	-	484	741	0.19	0.49
UB2	2016	-	-	-	-	-	-	-	-	-	-
	2017	2908	2030	-	-	-	-	1294	1859	0.44	0.92
	2018	3179	1666	-	-	-	-	2200	1627	0.69	0.98
	2019	2772	-	-	-	-	-	1508	-	0.54	-
UB3	2016	2899	2021	-	-	-	-	935	1625	0.32	0.80
	2017	3000	2053	-	-	-	-	970	1664	0.32	0.81
	2018	3281	1623	-	-	-	-	1031	1386	0.31	0.85
	2019	3026	-	-	-	-	-	406	-	0.13	-

Table 5. Annual mean air temperature (AMAT), annual mean ground surface temperature (AMGST), annual mean ground temperature (AMGT), surface offset (SO), nival offset (NO), and thermal offset (TO) summary metrics from air, ground surface, and ground (~1 m) temperatures at study sites (all values in °C). Metrics are calculated over hydrological years, from September 1 to August 31, with the Year column indicating the calendar year at the end of the hydrological year. Dashes indicate that no data are available.

Site	Year	AMAT	AMGST		AMGT		SO		NO		TO	
			B	UB	B	UB	B	UB	B	UB	B	UB
B1	2016	-0.7	4.3	4.3	0.0	0.0	5.0	5.0	14.4	12.5	-4.3	-4.3
	2017	-1.0	2.8	3.2	0.1	0.0	3.9	4.2	13.7	11.8	-2.7	-3.2
	2018	-2.3	4.1	3.3	0.7	-0.1	6.4	5.5	15.9	13.8	-3.2	-3.4
	2019	-2.3	1.8	2.4	0.0	-	4.1	4.7	19.3	-	-1.8	-
B2	2016	-0.7	4.8	-	4.4	3.3	5.5	-	12.4	9.9	-0.5	-
	2017	-1.0	4.3	3.2	3.6	2.9	5.3	4.2	13.8	-	-0.7	-0.3
	2018	-2.3	4.7	-	4.4	2.9	7.0	-	18.4	9.3	-	-
	2019	-2.3	3.3	2.0	2.7	-	5.6	4.3	15.9	-	-0.6	-
B3	2016	-0.8	4.4	3.8	4.3	3.6	5.3	4.7	12.7	13.3	-0.1	-0.3
	2017	-1.6	4.3	4.0	3.9	3.3	5.9	5.6	13.3	13.6	-0.3	-0.7
	2018	-2.4	5.1	4.1	4.5	3.9	7.4	6.4	16.8	16.0	-0.5	-0.2
	2019	-2.7	3.7	-	3.3	3.4	6.4	-	12.6	-	-0.5	-
B4	2016	-0.9	3.7	-	-	-	4.6	-	11.6	-	-	-
	2017	-1.6	3.1	-	-	-	4.7	-	10.4	-	-	-
	2018	-2.6	2.8	-	-	-	5.4	-	12.6	-	-	-
	2019	-2.8	2.7	-	-	-	5.5	-	10.9	-	-	-
B5	2016	-0.9	2.9	-	-0.2	-	3.8	-	11.9	-	-3.2	-
	2017	-1.6	2.6	-	0.6	-	4.2	-	11.1	-	-1.9	-
	2018	-2.6	-	-	-	-	-	-	14.0	-	-	-
	2019	-2.8	3.9	-	3.1	-	6.7	-	13.8	-	-0.8	-
B6	2016	-0.9	3.6	-	0.4	-	4.5	-	12.8	-	-3.3	-
	2017	-1.6	2.8	-	0.4	-	4.4	-	11.6	-	-2.3	-
	2018	-2.6	3.8	-	1.8	-	6.4	-	14.6	-	-2.0	-
	2019	-2.8	3.1	-	-	-	5.9	-	13.2	-	-	-
B7	2016	-1.0	5.0	3.0	1.7	0.6	6.0	4.0	13.0	14.8	-3.3	-2.3
	2017	-1.8	4.1	3.2	2.1	1.6	5.9	5.1	13.4	15.0	-2.0	-1.6
	2018	-2.8	4.3	4.5	3.0	2.9	7.1	7.3	14.9	18.6	-1.3	-1.5
	2019	-3.0	3.5	3.3	2.4	2.3	6.5	6.3	13.0	17.2	-1.1	-1.0
B8	2016	-1.3	4.3	-	1.6	0.1	5.5	-	12.0	12.7	-2.7	-
	2017	-2.1	3.9	2.3	1.6	0.1	6.0	4.4	13.4	13.7	-2.2	-2.2
	2018	-3.1	-	-	2.5	0.2	6.1	-	15.9	13.9	-	-
	2019	-3.2	3.1	2.3	-	0.1	6.3	5.5	17.7	12.7	-	-2.2
B9	2016	-2.2	3.0	-	0.7	-	5.2	-	16.1	-	-2.3	-
	2017	-3.0	2.5	-	1.0	-	5.6	-	15.5	-	-1.5	-
	2018	-4.0	2.1	-	-	-	6.1	-	16.4	-	-	-

	2019	-4.2	1.5	-	-	-	5.8	-	16.8	-	-	-
B10	2016	-2.4	4.5	-	2.4	-	6.9	-	15.8	-	-2.1	-
	2017	-3.3	4.4	-	3.0	-	7.6	-	16.2	-	-1.3	-
	2018	-4.2	3.8	-	3.1	-	8.0	-	15.6	-	-0.7	-
	2019	-4.4	3.1	-	2.4	-	7.5	-	13.9	-	-0.7	-
B11	2016	-2.5	3.8	-	-	-	6.2	-	16.5	-	-	-
	2017	-3.3	4.3	-	-	-	7.6	-	17.8	-	-	-
	2018	-4.2	4.6	-	-	-	8.8	-	18.8	-	-	-
	2019	-4.5	-	-	-	-	-	-	-	-	-	-
B12	2016	-2.5	-	-	-0.2	0.6	-	-	11.9	14.1	-	-
	2017	-3.3	1.7	3.2	-0.2	2.5	5.0	6.5	13.5	17.0	-1.9	-0.7
	2018	-4.2	-	-	-0.4	2.1	-	-	14.6	16.6	-	-
	2019	-4.5	1.1	2.3	0.0	1.9	5.6	6.7	14.5	-	-1.2	-0.4
B13	2016	-2.5	2.7	2.3	-	-	5.2	4.7	14.9	16.4	-	-
	2017	-3.3	3.5	2.5	-	-	6.8	5.8	17.2	17.4	-	-
	2018	-4.2	4.0	3.0	3.7	1.4	8.2	7.3	18.5	18.4	-0.3	-1.7
	2019	-4.5	3.2	2.3	3.0	1.2	7.7	6.7	19.5	-	-0.1	-1.0
B14	2016	-	-	-	-	-	-	-	-	-	-	-
	2017	-2.7	2.9	-	-0.2	-	5.6	-	12.3	-	-3.1	-
	2018	-3.9	1.3	-	-0.8	-	5.1	-	11.9	-	-1.3	-
	2019	-4.3	1.4	-	-0.1	-	5.8	-	11.5	-	-1.5	-
B15	2016	-3.3	1.8	-	-	-	5.1	-	9.9	-	-	-
	2017	-5.7	0.7	-	-1.1	-	5.1	-	8.9	-	-0.5	-
	2018	-5.0	-0.4	-	-2.4	-	4.6	-	9.0	-	-2.0	-
	2019	-5.6	-0.5	-	-2.5	-	5.1	-	9.1	-	-2.0	-
B16	2016	-3.3	0.2	-	-	-	3.5	-	8.7	-	-	-
	2017	-5.7	-1.0	-	-1.1	-	4.7	-	9.2	-	-0.1	-
	2018	-5.0	-1.9	-	-1.9	-	3.0	-	7.5	-	0.0	-
	2019	-5.6	-2.5	-	-1.8	-	3.0	-	6.5	-	0.8	-
UB1	2016	-	-	-	-	-	-	-	-	-	-	-
	2017	-	-	-	-	-	-	-	-	-	-	-
	2018	-2.2	-	1.1	-	-0.6	-	3.3	-	12.5	-	-1.7
	2019	-2.3	-	0.9	-	-0.5	-	3.4	-	10.4	-	-1.4
UB2	2016	-	-	-	-	-	-	-	-	-	-	-
	2017	-2.6	-	1.3	-	-0.9	-	3.9	-	7.6	-	-2.2
	2018	-3.5	-	-1.0	-	-1.3	-	2.4	-	4.8	-	-0.2
	2019	-3.6	-	0.1	-	-0.6	-	3.7	-	6.6	-	-0.7
UB3	2016	-2.2	-	-	-	-0.8	-	-	-	9.4	-	-
	2017	-2.6	-	1.7	-	-0.8	-	4.3	-	9.6	-	-2.6
	2018	-3.9	-	1.5	-	-1.0	-	5.3	-	11.3	-	-2.5
	2019	-4.3	-	2.2	-	-0.6	-	6.5	-	12.5	-	-2.7

Table 6. Annual maximum snow depth and total snow depth days at study sites. Dashes indicate that no data are available. Sites B2, B11, B15, and B16 are not included as no data are available.

Site	Year	Maximum snow depth (cm)	Snow depth days (m days)
B1	2016	55	58
	2017	55	38
	2018	70	71
	2019	45	38
B3	2016	45	49
	2017	55	42
	2018	55	66
	2019	45	49
B4	2016	-	-
	2017	-	-
	2018	70	71
	2019	55	52
B5	2016	45	47
	2017	55	37
	2018	70	65
	2019	45	44
B6	2016	45	46
	2017	55	45
	2018	55	61
	2019	55	57
B7	2016	45	44
	2017	70	47
	2018	55	68
	2019	55	47
B8	2016	55	55
	2017	70	60
	2018	70	73
	2019	55	53
B9	2016	70	101
	2017	70	69
	2018	70	64
	2019	100	57
B10	2016	70	71
	2017	70	82
	2018	-	-
	2019	55	45
B12	2016	45	59
	2017	70	74
	2018	55	66
	2019	70	50
B13	2016	55	60
	2017	70	66
	2018	50	61
	2019	55	46
B14	2016	-	-
	2017	-	-
	2018	-	-
	2019	55	45
UB1	2016	-	-
	2017	-	-
	2018	70	91
	2019	55	52
UB2	2016	-	-
	2017	-	-
	2018	-	-
	2019	45	55
UB3	2016	45	49
	2017	70	54
	2018	45	46
	2019	45	48

Soil conditions

Soil samples from the active layer and upper permafrost were collected at most sites using a motorized SIPRE corer with a 75 mm diameter core barrel. At certain sites where coring was not possible due to substrate conditions or logistical constraints, soil samples were collected from pits that were dug within the active layer. Samples were packaged and shipped in original frozen (permafrost) or unfrozen (active layer) condition to the University of Ottawa for laboratory analysis, including estimates of excess ice content (EIC), bulk density (bD), gravimetric moisture content (GMC), grain size distribution, and organic matter content (Tables 7 and 8). Samples were sectioned into increments of up to 15 cm to allow for characterization along the soil profile.

Excess ice content

Excess ice refers to ice that is present in excess of the thawed soil's pore space and is commonly determined by measuring the volume of supernatant water after a sample is thawed (French 2017, Lewkowicz et al. 2024). Permafrost samples were placed into glass beakers, weighed (W_w), and allowed to thaw and settle for 24 hours. Once the samples had thawed, the volumes of supernatant water (W_v) versus sediment (S_v) were measured, and excess ice (EIC) was calculated using the following equation:

$$EIC(\%) = \left[\frac{W_v \times 1.09}{S_v + (W_v \times 1.09)} \right] \times 100$$

where W_v is the volume of supernatant water (cm^3), multiplied by 1.09 to estimate the equivalent volume of ice, and S_v is the volume of saturated sediment (cm^3) (Kokelj and Burn 2003).

Dry bulk density

The samples were dried at 105°C for 24 hours and then weighed (W_d). Bulk density (bD) was calculated using the following equation:

$$bD = \frac{W_d}{S_v + W_v}$$

where W_d is the dry mass of the sample (g), S_v is the volume of saturated sediment (cm^3), and W_v is the volume of supernatant water (cm^3).

Gravimetric moisture content

The sample's wet (W_w) and dry (W_d) masses were compared to calculate gravimetric moisture content, (van Everdingen 2005):

$$GMC(\%) = \left[\frac{W_w - W_d}{W_d} \right] \times 100$$

where W_w is the wet mass (g) and W_d is the dry mass (g) of the sample.

Mean grain size and grain size distribution

Dry samples were passed through a 2 mm sieve to determine the proportion of gravel present in the sample. Only three sites had particles >2 mm, and at two of these (B9 and B13),

gravel made up less than 10% of the total sample. At B8, the soil profile contained 36-86% gravel. Once this coarse fraction was removed, grain size distributions were determined using a Microtrac S3500 Laser Particle Size Analyzer (LPSA), which measures particles from 0.02 to 2800 μm in diameter. Organic matter was removed from the fine fraction using 30% hydrogen peroxide (H_2O_2) (Verret et al. 2019), as the LPSA does not differentiate between mineral and organic material. The remaining mineral soil sample was dispersed using a 5% hexametaphosphate solution before a sample aliquot was introduced into the LPSA chamber. Duplicates were analyzed for 5% of the samples to evaluate the precision of the instrument, which was within 2–4%. The LPSA generated a grain size distribution for each sample as sand, silt, and clay, along with an estimate of the mean sediment grain size in μm .

Organic matter content

Loss on ignition was performed using a LECO thermo-gravimetric analyzer with an integrated balance (model TGA701). Subsamples were placed in crucibles within the instrument and then subjected to increases in temperature up to 105°C to ensure that the sample was dry and up to 550°C for combustion of organic matter. The samples were weighed at 105°C and 550°C, when the variation in sample mass reached 0.1%. The accuracy of the loss on ignition analysis was determined from a calcium oxalate standard, with an analytical error of $\pm 0.13\%$. The organic matter content was calculated using the following equation:

$$\text{Organic matter content (\%)} = (LOI_{105} - \frac{LOI_{550}}{LOI_{105}}) \times 100$$

where LOI_{105} is the mass of the sample at 105°C (g) and LOI_{550} is the mass of the sample at 550°C (g).

These soil and core characteristics are useful for characterizing the study sites, understanding the frost susceptibility of these sites, and parameterizing thermal modelling efforts for this study region.

Table 7. Sediment characteristics from soil and core samples collected in 2016 or soil pits dug in 2016 or 2017. Mean sediment grain size, proportion of sediment as gravel, sand, silt, or clay, and organic content are presented for mineral samples. Bulk density, gravimetric moisture content, and excess ice content are presented for organic and mineral samples, where data is available. Dashes indicate that no data are available. Sites B15, B16, and UB1 are not included as no data are available.

Site	Depth (cm)	Soil type	Mean grain size (μm)	Grain size proportion (%)			Organic content (%)	Bulk density (kg/m^3)	Gravimetric moisture content (%)	Excess ice content (%)
				Sand	Silt	Clay				
B1	24-39	Organic	-	-	-	-	-	0.2	639	0
	39-53	Organic	-	-	-	-	-	0.2	509	0
	55-65	Organic	-	-	-	-	-	0.2	553	0
	65-78	Organic	-	-	-	-	-	0.1	1253	0
	78-94	Organic	-	-	-	-	-	0.1	1476	0
	94-100	Organic	-	-	-	-	-	0.1	922	13
	100-117	Organic	-	-	-	-	-	0.1	907	0
	117-129	Organic	-	-	-	-	-	0.1	789	0
	145-159	Organic	-	-	-	-	-	0.1	150	0
	159-174	Organic	-	-	-	-	-	0.1	671	0
	174-189	Organic	-	-	-	-	-	0.1	790	0
	189-203	Organic	-	-	-	-	-	0.1	814	0
	203-214	Organic	-	-	-	-	-	0.1	864	0
	214-225	Organic	-	-	-	-	-	0.1	971	0
	225-238	Organic	-	-	-	-	-	0.1	768	0
	238-251	Organic	-	-	-	-	-	0.1	860	0
	251-263	Organic	-	-	-	-	-	0.1	626	0
	263-275	Organic	-	-	-	-	-	0.2	332	0
	275-297	Mineral	55	26	64	10	21.1	0.2	239	8
	297-310	Mineral	21	7	66	27	6.9	0.8	89	7
B2	20	Mineral	-	-	-	-	-	-	345	0
	40	Mineral	193	92	9	0	1.5	-	24	0
B3	0-15	Mineral	-	-	-	-	-	-	216	0
	30-35	Mineral	85	65	29	6	1.2	-	6	0
B4	0-16	Organic	-	-	-	-	-	-	121	0
	16-20	Mineral	52	34	60	6	1.9	-	11	0
	20	Mineral	51	24	65	9	2.6	-	21	0
	35	Mineral	56	32	61	8	1.7	-	11	0
	56	Mineral	51	41	41	18	2.1	-	11	0
B5	25	Mineral	56	31	61	8	1.7	-	17	0
	35-40	Mineral	53	27	64	9	2.2	-	23	0
	43-58	Mineral	54	29	64	8	1.3	-	59	29
	50	Mineral	64	41	52	7	3.8	-	29	0
	58-72	Mineral	65	41	54	5	1.2	-	41	24
	72-86	Mineral	86	51	46	3	0.9	-	40	18
B6 (1)	50	Mineral	79	85	14	1	48.4	-	36	0
	60-65	Mineral	112	66	27	7	2.0	-	13	0
	75	Mineral	12	30	37	32	3.3	-	20	0
	100	Mineral	33	26	42	32	2.9	-	16	0
B6 (2)	70-82	Organic	-	-	-	-	-	0.2	503	0
	82-93	Organic	-	-	-	-	-	0.2	513	0
	93-108	Organic	-	-	-	-	-	0.2	446	11
	108-122	Organic	-	-	-	-	-	0.3	365	13
	125-137	Organic	-	-	-	-	-	0.2	461	11
	137-141	Organic	-	-	-	-	-	0.2	462	0
B7	35	Mineral	184	79	20	2	1.3	-	12	0
	45-50	Mineral	206	79	20	1	6.7	-	16	0
B8	15	Organic	-	-	-	-	-	-	336	0
	35-40	Mineral	206	82	16	2	2.5	-	6	0
	40	Mineral	185	75	21	4	2	-	14	0
B9 (1)	10-15	Mineral	218	76	20	5	-	-	7	0
B9 (2)		Organic	-	-	-	-	-	-	332	0
	35	Organic	-	-	-	-	-	-	483	0
	75	Mineral	-	-	-	-	1	-	-	0
B10	30	Mineral	-	-	-	-	-	-	47	0
	38	Mineral	273	85	15	1	2	-	11	0

	50	Mineral	513	91	9	0	2.7	-	5	0
B11	25	Mineral	460	96	4	0	0.5	-	13	0
B12	38	Organic	-	-	-	-	-	-	427	0
	15	Organic	-	-	-	-	-	-	485	0
B13	30	Mineral	564	95	5	0	0.7	-	20	0
	50	Mineral	-	81	17	2	-	-	-	0
	0-18	Organic	-	-	-	-	-	-	123	0
	18-31	Organic	-	-	-	-	-	-	316	0
	31-64	Organic	-	-	-	-	-	-	467	0
	50	Organic	-	-	-	-	-	-	334	0
	64-93	Organic	-	-	-	-	-	-	569	0
	93-99	Organic	-	-	-	-	-	-	588	0
	99-124	Organic	-	-	-	-	-	-	372	0
B14	124-153	Organic	-	-	-	-	-	-	520	0
	153-167	Organic	-	-	-	-	-	-	237	0
	167-199	Organic	-	-	-	-	-	-	492	0
	199-218	Organic	-	-	-	-	-	-	264	0
	239-254	Organic	-	-	-	-	-	-	322	0
	254-289	Organic	-	-	-	-	-	-	278	0
	289-312	Mineral	26	10	58	33	7.3	-	120	40
	312-325	Mineral	58	30	44	26	3.6	-	82	30
	0-15	Organic	-	-	-	-	-	-	429	0
	15-20	Organic	-	-	-	-	-	0.1	12307	84
	20-35	Organic	-	-	-	-	-	0.1	736	0
	35-47	Organic	-	-	-	-	-	0.2	313	0
	47-58	Mineral	31	15	64	21	12.4	0.7	79	10
	58-70	Mineral	31	16	62	22	2.7	1.0	59	17
	60	Mineral	-	-	-	-	-	-	380	0
UB2	70-82	Mineral	43	27	60	14	1.8	1.0	65	29
	82-91	Mineral	40	21	66	13	2	1.0	61	27
	91-103	Mineral	27	11	72	17	1.6	1.0	46	16
	103-115	Mineral	24	9	74	18	1.7	0.8	46	30
	115-121	Mineral	33	14	69	17	2.2	-	87	46
	121-133	Mineral	31	13	69	17	2.2	0.7	87	42
	133-143	Mineral	33	14	72	14	2	0.7	89	36
	143-153	Mineral	-	17	72	12	1.4	1.4	-	0
	0-4	Organic	-	-	-	-	-	-	153	0
	4-9	Organic	-	-	-	-	-	-	655	0
	9-19	Organic	-	-	-	-	-	-	700	0
	25-33	Organic	-	-	-	-	-	-	759	0
	33-50	Organic	-	-	-	-	-	-	379	0
	45-50	Organic	-	-	-	-	-	-	537	0
	50-60	Organic	-	-	-	-	-	-	650	0
	60-70	Organic	-	-	-	-	-	-	981	0
	70-81	Organic	-	-	-	-	-	-	1067	0
UB3	81-90	Organic	-	-	-	-	-	-	795	0
	90-99	Organic	-	-	-	-	-	-	805	0
	99-110	Organic	-	-	-	-	-	-	696	0
	110-120	Organic	-	-	-	-	-	-	700	0
	120-130	Organic	-	-	-	-	-	-	606	0
	130-145	Organic	-	-	-	-	-	-	635	0
	145-161	Organic	-	-	-	-	-	-	574	0
	161-175	Organic	-	-	-	-	-	-	597	0
	175-185	Organic	-	-	-	-	-	-	555	0
	185-195	Organic	-	-	-	-	-	-	387	0
	218-239	Organic	-	-	-	-	-	-	469	0

Table 8. Summary of sample type and number, mean sediment grain size of mineral samples, proportion of sediment as gravel, sand, silt, or clay, organic matter content of mineral samples, bulk density, gravimetric moisture content, and excess ice content from soil and core samples at the study sites. Dashes indicate that no data are available. Sites B15, B16, and UB1 are not included as no data are available.

Site	Soil type	Depth (cm)	Number of samples	Mean grain size (μm)	Grain size proportion (%)			Organic matter content (%)	Bulk density (kg/m^3)	Gravimetric moisture content (%)	Excess ice content (%)
					Sand	Silt	Clay				
B1	Organic	24-275	18	-	-	-	-	-	0.1	772	0.7
	Mineral	275-310	2	38	16	65	19	14.0	0.5	164	7.5
B2	Mineral	20-40	2	193	92	9	0	1.5	-	185	0
B3	Mineral	0-35	2	85	65	29	6	1.2	-	111	0
B4	Organic	0-16	1	-	-	-	-	-	-	121	0
	Mineral	16-56	4	53	33	57	10	2.1	-	13	0
B5	Mineral	25-86	6	63	37	57	7	1.9	-	35	11.8
B6	Organic	70-141	6	-	-	-	-	-	0.2	458	0
	Mineral	50-100	4	59	52	30	18	14.2	-	21	5.8
B7	Mineral	35-50	2	195	79	20	2	4.0	-	14	0
B8	Organic	15	1	-	-	-	-	-	-	336	0
	Mineral	35-40	2	196	79	19	3	2.3	-	10	0
B9	Organic	35	2	-	-	-	-	-	-	408	0
	Mineral	10-75	2	218	76	20	5	1.0	-	7	0
B10	Mineral	30-50	3	393	88	12	1	2.4	-	21	0
B11	Mineral	25	1	460	96	4	0	0.5	-	13	0
B12	Organic	38	1	-	-	-	-	-	-	427	0
B13	Organic	15	1	-	-	-	-	-	-	485	0
	Mineral	30-50	2	564	88	11	1	0.7	-	20	0
B14	Organic	0-289	13	-	-	-	-	-	-	376	0
	Mineral	289-325	2	42	20	51	30	5.4	0.2	101	35
UB2	Organic	0-47	4	-	-	-	-	-	0.1	3446	21
	Mineral	47-153	11	33	16	68	17	3.0	0.9	100	23
UB3	Organic	0-239	20	-	-	-	-	-	-	635	0

Ecological characteristics and conditions

Pre-burn conditions were inferred from long-term climate records, measurements at the three unburned sites, and at the unburned portions of some burned sites. Burn severity varied both between and within sites.

The depth of burn and burn severity were derived from the heights of black spruce adventitious roots and the residual soil organic layer (Table 9). Black spruce adventitious roots provide an estimate of the thickness of the organic mat that was consumed in the fire (Kasischke and Johnstone 2005, Boby et al. 2010). Three adventitious root heights were measured at 2 m intervals along 80 or 160 m-long linear transects, where a black spruce tree was present within 2 m. Residual soil organic layer thicknesses were assessed by digging small pits at each site. The depth of burn was calculated using the following equation (Walker et al. 2018):

$$\text{Depth of Burn} = \text{Measured ARH} + \text{Unburned ARH} + (0.03 \times \text{SOL})$$

where ARH is the adventitious root height (cm), the unburned ARH from adjacent unburned stands is 3.7 cm (Walker et al. 2018), and SOL is the residual soil organic layer thickness (cm). The proportion of organic layer lost to fire varied from 6 to 68%, with sites with thicker pre-fire organic layers seeing lower proportions of loss. The depth of burn at the sites varied from 9 to 36 cm, representing moderate to high burn severity.

Table 9. Mean adventitious root height, residual soil organic layer, depth of burn, pre-fire organic layer thickness, and proportion of organic layer lost at eight study sites. Sites B2, B3, B6, B7, B11, B14, B15, and B16 are not included as no data are available.

Site	Mean adventitious root height (cm)	Residual soil organic layer (cm)	Estimated depth of burn (cm)	Estimated pre-fire organic layer thickness (cm)	Percent of organic layer lost (%)
B1	5	297	18	315	6
B4	17	10	21	31	68
B5	5	20	9	29	32
B8	9	21	13	34	39
B9	9	80	15	95	16
B10	31	28	36	64	56
B12	5	101	12	113	11
B13	4	33	9	42	21

Acknowledgements

Financial support for the collection of this field data was provided by the Government of Northwest Territories Cumulative Impact Monitoring Program (Project #170), the Natural Sciences and Engineering Research Council Discovery Grant Program, the Weston Family Foundation, the Northern Scientific Training Program, the Royal Canadian Geographical Society, the University of Ottawa, and the Geological Survey of Canada. Field logistics support was provided by Steven Cumming. Field assistance was provided by Kirsten Reid, Lucas Brehaut, Nicola Day, Xanthe Walker, Geneviève Degré-Timmons, Julie Trus, Tom Douglas, Catherine Dieleman, Brittany Main, Kevin Stones, Moya Painter, and Tracy Holloway. Brendan O'Neill provided helpful comments.

References

- Boby, L.A., Schuur, E.A.G., Mack, M.C., Verbyla, D., and Johnstone, J.F. 2010. Quantifying fire severity, carbon, and nitrogen emissions in Alaska's boreal forest. *Ecological Applications*, **20**(6): 1633–1647. doi:10.1890/08-2295.1.
- Environment and Climate Change Canada. 2025. Canadian Climate Normals.
- van Everdingen, R. (*Editor*). 2005. Multi-language glossary of permafrost and related ground-ice terms. National Snow and Ice Data Center, Boulder, Colorado, USA.
- French, H.M. 2017. *The Periglacial Environment*, 4th Edition. Wiley-Blackwell.
- Gibson, C.M., Chasmer, L.E., Thompson, D.K., Quinton, W.L., Flannigan, M.D., and Olefeldt, D. 2018. Wildfire as a major driver of recent permafrost thaw in boreal peatlands. *Nature Communications*, **9**(1): 3041. doi:10.1038/s41467-018-05457-1.
- Government of Northwest Territories. 2008. Ecosystem classification.
- Heginbottom, J.A., Dubreuil, M.-A., and Harker, P. 1995. Canada, Permafrost (National Atlas of Canada, 5th Edition). Natural Resources Canada,. doi:10.4095/294672.
- Heiri, O., Lotter, A.F., and Lemcke, G. 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: Reproducibility and comparability of results. *Journal of Paleolimnology*, **25**: 101–110. doi:10.1023/A:1008119611481.
- Holloway, J. 2020. Impacts of forest fire on permafrost in the discontinuous zones of northwestern Canada. PhD, University of Ottawa, Ottawa, Canada.
- Karunaratne, K.C., and Burn, C.R. 2004. Relations between air and surface temperature in discontinuous permafrost terrain near Mayo, Yukon Territory. *Canadian Journal of Earth Sciences*, **41**(12): 1437–1451. doi:10.1139/e04-082.
- Kasischke, E.S., and Johnstone, J.F. 2005. Variation in postfire organic layer thickness in a black spruce forest complex in interior Alaska and its effects on soil temperature and moisture. *Canadian Journal of Forest Research*, **35**(9): 2164–2177. doi:10.1139/x05-159.
- Klene, A.E., Nelson, F.E., Shiklomanov, N.I., and Hinkel, K.M. 2001. The n-factor in natural landscapes: Variability of air and soil-surface temperatures, Kuparuk River Basin, Alaska, U.S.A. *Arctic, Antarctic, and Alpine Research*, **33**(2): 140–148. doi:10.1080/15230430.2001.12003416.
- Kokelj, S.V., and Burn, C.R. 2003. Ground ice and soluble cations in near-surface permafrost, Inuvik, Northwest Territories, Canada. *Permafrost and Periglacial Processes*, **14**(3): 275–289. doi:10.1002/ppp.458.

- Lewkowicz, A., Wolfe, S., Roujanski, V., Hoeve, E., O'Neill, H.B., Gruber, S., Roy-Léveillé, P., Brown, N., Koenig, C., Brooks, H., Rudy, A., Bonnaventure, P., and Paquette, M. 2024. An illustrated permafrost dictionary. Canadian Permafrost Association (CPA).
- Lewkowicz, A.G. 2008. Evaluation of miniature temperature-loggers to monitor snowpack evolution at mountain permafrost sites, northwestern Canada. *Permafrost and Periglacial Processes*, **19**(3): 323–331. doi:10.1002/ppp.625.
- Morse, P.D., Wolfe, S.A., Kokelj, S.V., and Gaanderse, A.J.R. 2016. The occurrence and thermal disequilibrium state of permafrost in forest ecotopes of the Great Slave Region, Northwest Territories, Canada. *Permafrost and Periglacial Processes*, **27**(2): 145–162. doi:10.1002/ppp.1858.
- Northwest Territories Centre for Geomatics. 2015. Fire history.
- Riseborough, D.W., and Burgess, M.M. 1996. Measurement interval and the accurate assessment of ground temperature trends. *Permafrost and Periglacial Processes*, **7**(4): 321–335. doi:10.1002/(SICI)1099-1530(199610)7:4<321::AID-PPP233>3.0.CO;2-J.
- Smith, M.W., and Riseborough, D.W. 2002. Climate and the limits of permafrost: A zonal analysis. *Permafrost and Periglacial Processes*, **13**(1): 1–15. doi:10.1002/ppp.410.
- Smith, S.L., Burgess, M.M., and Riseborough, D.W. 2008. Ground temperature and thaw settlement in frozen peatlands along the Norman Wells Pipeline Corridor, NWT Canada: 22 years of monitoring. *In* Proceedings of the 9th International Conference on Permafrost. Institute of Northern Engineering, University of Alaska Fairbanks. pp. 1665–1670.
- Smith, S.L., Riseborough, D.W., and Bonnaventure, P.P. 2015. Eighteen year record of forest fire effects on ground thermal regimes and permafrost in the Central Mackenzie Valley, NWT, Canada. *Permafrost and Periglacial Processes*, **26**(4): 289–303. doi:10.1002/ppp.1849.
- Verret, M., Wang, Y., Bjornson, J., and Lacelle, D. 2019. Hummocks in alpine tundra, northern British Columbia, Canada: distribution, morphology and organic carbon composition. *Arctic Science*, **5**(3): 127–147. doi:10.1139/as-2018-0021.
- Walker, X.J., Baltzer, J.L., Cumming, S.G., Day, N.J., Johnstone, J.F., Rogers, B.M., Solvik, K., Turetsky, M.R., and Mack, M.C. 2018. Soil organic layer combustion in boreal black spruce and jack pine stands of the Northwest Territories, Canada. *International Journal of Wildland Fire*, **27**(2): 125. doi:10.1071/WF17095.
- Way, R.G., Lewkowicz, A.G., and Zhang, Y. 2018. Characteristics and fate of isolated permafrost patches in coastal Labrador, Canada. *The Cryosphere*, **12**(8): 2667–2688. doi:10.5194/tc-12-2667-2018.
- Wolfe, S.A., Morse, P.D., Hoeve, T.E., Sladen, W.E., Kokelj, S.V., and Arenson, L.U. 2015. Disequilibrium permafrost conditions on NWT Highway 3. *In* Proceedings of GeoQuebec 2015. Quebec, Canada. pp. 1–8.