

Plant belowground traits indicate increased plant-mediated methane transport along a peatland permafrost thaw gradient

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Abstract. Permafrost thaw alters methane (CH₄) fluxes from subarctic peatland ecosystems. Collapsing permafrost palsas change hydrology, interstitial oxygen availability, and vegetation composition, and each of these factors contribute to net CH₄ flux by influencing CH₄ production, consumption and transport. Changes in plant-mediated CH₄ fluxes have mostly been estimated using aboveground characteristics, such as biomass and leaf area, leaving belowground parts (roots and rhizomes) understudied despite their direct contact to depth-dependent CH₄ flux processes. Here, we explored the potential of using root and rhizome traits as proxies for plant-mediated CH₄ cycling along a peatland permafrost thaw gradient in subarctic Sweden. We investigated changes in root and rhizome biomass, surface area (SA), diameter, tissue density (TD), and specific root length (SRL) along the permafrost thaw gradient, and how these traits relate to early-, middle-, peak- and season median CH₄ fluxes. We utilized chamber CH₄ flux and pore water CH₄ concentration and isotopic measurements during the productive season. Shrub SRL, diameter and isotopic data suggested increased plant-mediated carbon substrates available for acetoclastic methanogenesis across the thaw gradient. Root TD, proxy for root porosity, decreased with thaw and had negative correlations with CH₄ fluxes throughout the season. Simultaneously, herbaceous rhizome SA-CH₄ flux correlations were positive and pore water CH₄ concentrations were lowest in the fully thawed stage. These results indicated increasing herbaceous plant-mediated transport of acetoclastically-produced CH₄ with thaw. Our study demonstrates that integrating plant belowground traits with environmental and biogeochemical data can help improve CH₄ flux predictions in thawing landscapes and revealed key mechanistic insights regarding the interplay between substrate availability for methanogenesis and gas transport.

1 Introduction

Northern peatlands are significant net methane (CH₄) emitters primarily due to the predominance of anoxia throughout the peat depth profile (Gorham, 1991; McGuire et al., 2009; Zhuang et al., 2004). Owing to high organic carbon accumulation, high-latitude peatlands store approximately a third of the global carbon stock (Gorham, 1991), with a substantial fraction preserved in and beneath permafrost (Schuur et al., 2008). In the high latitudes, increasing air temperatures drive permafrost thaw, which can expose the previously frozen organic matter to soil decomposers, including methanogens. Together with altered hydrological and thermal conditions, these processes may increase CH₄ emissions and lead to positive climate feedback (Olefeldt et al., 2013; Schuur et al., 2008). Palsa mires with permafrost plateaus (palsas) are especially vulnerable to increasing temperatures and changes in precipitation (Luoto et al., 2004). Palsas are approximately 0.5-10 m high peat hummocks with a frozen core of peat and mineral soil. They form as a result of water-saturated peat freezing in winter and the dry surface peat protecting the frozen peat in summer, raising the peat above the surrounding mire (Luoto et al., 2004). In northern Fennoscandia, permafrost thaw has formed transitional gradients from frozen palsas and peat plateau to permafrost-free bogs and fens (Luoto et al., 2004; Olvmo et al., 2020). Following palsa collapse, soil moisture increases, shifting the system from an ombrotrophic bog-like system to a minerotrophic fen. Vegetation composition shifts from shrub-dominated on palsas to graminoid-dominated in fens, and soil redox and pH change, influencing methanogenic CH₄ production, methanotrophic CH₄ consumption, and CH₄ transport from the soil to the atmosphere, and net CH₄ fluxes (Perryman et al., 2020; Turetsky et al., 2014; Varner et al., 2022). Almost all arctic permafrost has been estimated to degrade and result in 120 ± 85 Gt of carbon emissions by 2100 (Lawrence et al., 2008; Schaefer et al., 2014). Together with the inevitable disappearance of palsa mires (Luoto et al., 2004; Olvmo et al., 2020), this highlights the urgent need to investigate the network of CH₄ flux controls in thawing palsa mires.

One of the key biotic CH₄ flux drivers in permafrost peatlands are wetland plants and the traits reflecting their adaptive and resource acquisition strategies. In general, plants contribute to CH₄ fluxes by mediating gas transport, providing carbon substrates for methanogens, and modifying the physicochemical properties of the rhizosphere (Chanton & Dacey, 1991; Laanbroek, 2010; Määtä & Malhotra, 2024; Noyce et al., 2014). As an adaptive strategy to anoxia, many wetland plant species develop aerenchyma which are air spaces within the plant stem, roots and rhizomes that transport oxygen (O₂) from the atmosphere to the roots and the surrounding soil (Armstrong et al., 1991; Končalová, 1990; Vroom et al., 2022). This plant-mediated gas transport mechanism enhances rhizosphere oxygenation and CH₄ consumption, but also simultaneously increases CH₄ transport from anoxic peat to the atmosphere (Laanbroek, 2010; Noyce et al., 2014; Ström et al., 2005). While peatlands store vast quantities of carbon, much of it is too recalcitrant to be directly utilized by methanogens particularly in deep peat

60 (Hogg, 1993; Ström et al., 2005). The release of labile carbon substrates such as acetate and other organic acids by plant roots stimulates CH₄ production and emission (Joabsson & Christensen, 2001; Ström et al., 2003).

Studies using plant functional traits to predict CH₄ fluxes have primarily focused on aboveground features, such as plant green area, even though plant belowground biomass can exceed that aboveground especially in (sub)arctic ecosystems (Iversen et al., 2015; Malhotra & Roulet, 2015). Often, the aboveground traits have been used to estimate belowground characteristics, 65 such as root porosity, based on the plant species or functional type (PFT) (e.g., Bouchard et al., 2007; Greenup et al., 2000; Iversen et al., 2015). However, above- and belowground plant traits and the functional connections between them have not been adequately studied in relation to carbon cycling and the use of aboveground traits as proxies for plant-mediated belowground carbon functioning remains unresolved (Iversen et al., 2015; Määttä & Malhotra, 2024).

Many studies have used above- and/or belowground biomass as CH₄ flux predictors but the direction of the relationship varies 70 strongly between studies, species, and PFTs (e.g., Greenup et al., 2000; Joabsson & Christensen, 2001; Koelbener et al., 2010). While above and belowground biomass may reflect plant productivity, quantification of plant-mediated CH₄ fluxes may be better served by a knowledge of belowground traits more directly related to CH₄ production, consumption and transport. For example, root exudation in some instances can explain CH₄ flux variation better than biomass (Ström et al., 2005; Waldo et al., 2019). Because belowground traits, such as rooting depth, change with a deepening active layer (Blume-Werry et al., 2016; 75 Iversen et al., 2015), assessing these trait variations and their effects on CH₄ fluxes along permafrost thaw gradients is essential.

Wetland CH₄ fluxes can be driven by plant-mediated carbon release and CH₄ and O₂ transport (Knox et al., 2021), which can be reflected in root and rhizome traits. Increases in root and rhizome tissue porosity (i.e., lower tissue density and larger diameter; Freschet et al., 2021a; Visser et al., 2000) can enhance plant-mediated gas transport and, depending on species and environmental conditions (e.g., water table level), can lead to increased CH₄ transport and net flux (Bhullar et al., 2013; 80 Henneberg et al., 2016; van den Berg et al., 2020) or rhizospheric CH₄ oxidation and decreased net CH₄ flux (e.g., Fritz et al., 2011; Noyce et al., 2023). CH₄ production can be stimulated by increased labile carbon provision particularly from root exudation (Ström et al., 2003, 2012; Waldo et al., 2019) but also from rhizome and root decomposition (Hackney & De La Cruz, 1980; Scheffer & Aerts, 2000). Specific root length (SRL), the relationship between root length and dry mass, could be a proxy for carbon substrate provision, as high SRL is associated with low tissue density, shorter lifespan, high turnover rates 85 (Bergmann et al., 2020; Eissenstat et al., 2000), and root exudation (Wen et al., 2022). However, studies on the relationships between different root traits, especially SRL and tissue density, in wetlands are rare (Iversen et al., 2015; Pan et al., 2019).

Here, we investigated 1) how root (biomass, surface area, diameter, tissue density, and SRL) and rhizome (biomass, surface area, diameter, and tissue density) traits vary along a peatland permafrost thaw gradient, 2) the correlation of these belowground traits with CH₄ fluxes, and 3) whether root and rhizome traits are strong predictors of CH₄ flux during early, middle and peak 90 CH₄ flux during the productive season. We expected that root biomass, surface area and SRL would be highest at the intact

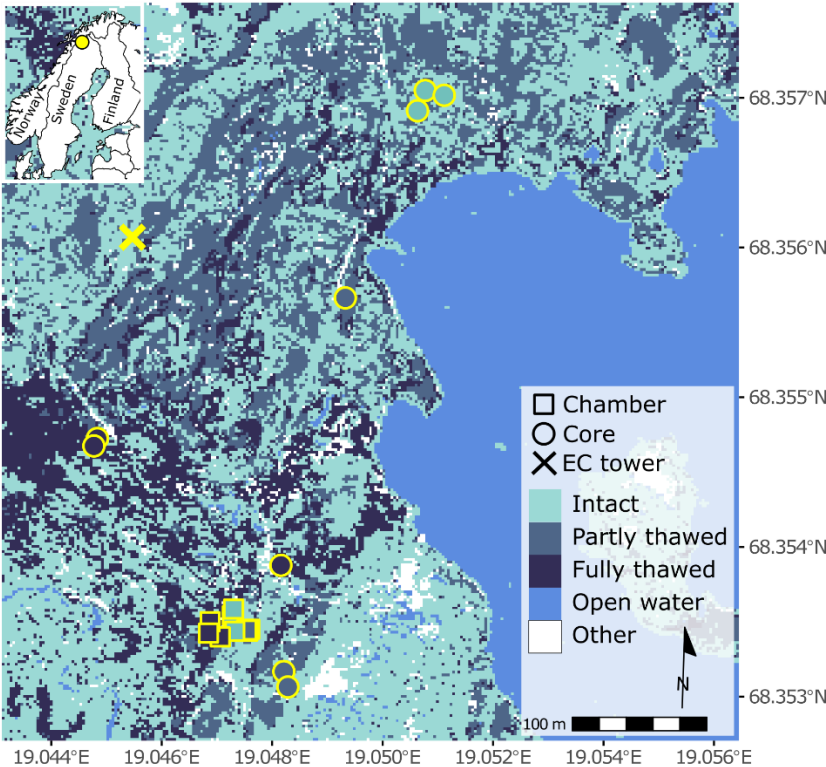
and partly thawed permafrost stages due to lower soil moisture and high species diversity (Hough et al., 2022; Iversen et al., 2015; Keuper et al., 2017). We hypothesized that shrub rhizomes would be most abundant in the intact permafrost stage, whereas most herbaceous rhizome biomass would be found in the more thawed permafrost stage (Hough et al., 2022). We hypothesized that root and rhizome tissue density would decrease from intact to fully thawed permafrost due to increased soil moisture. We also expected that SRL would increase CH₄ flux (Saarnio et al., 2004; Ström & Christensen, 2007; Wen et al., 2022), while tissue density would have negative relationships with CH₄ fluxes throughout the productive season. We expected the trait-CH₄ flux relationships to be stronger for herbaceous plants than for shrubs at the middle and peak CH₄ flux periods, because herbaceous plants increase root biomass throughout the growing season in the tundra (Billings et al., 1978; Kummerow & Russell, 1980; Wang et al., 2016) whereas shrub root biomass can remain relatively constant (Wang et al., 2016).

2 Materials and methods

2.1 Study area

The study area is the Stordalen mire in northern Sweden (68° 22' N 19° 03' E; Fig. 1). The mean annual temperature of the area was -0.5 °C and mean annual precipitation sum was 204 mm for period 1985-2023, based on measurements from a nearby meteorological station (Polarforskningssekretariatet & SMHI, 2025a, 2025b). The area contains a permafrost thaw gradient ranging from palsa with intact permafrost to partly and fully thawed permafrost, each of which includes hydrological conditions and vegetation compositions typical for each thaw stage. The permafrost is largely intact in drained palsa with ericaceous shrubs (e.g., *Empetrum nigrum*, *Andromeda polifolia*, *Rubus chamaemorus*), hummock-forming *Eriophorum vaginatum*, mosses (e.g., *Dicranum* sp.) and lichens (Holmes et al., 2022; Hough et al., 2021; Malhotra & Roulet, 2015). In the partly thawed hydrologically perched stage, the vegetation is dominated by *Sphagnum* spp. and feather mosses as well as sedges, such as *Eriophorum vaginatum* and *Carex rotundata*, typical for ombrotrophic bogs (Holmes et al., 2022; Malhotra & Roulet, 2015). The fully thawed stage includes wet minerotrophic fens that have generally higher pH and their dominant vegetation includes *Eriophorum angustifolium*, *Equisetum fluviatile* and *Carex rostrata* (Holmes et al., 2022; Johansson et al., 2006; Malhotra & Roulet, 2015). In general, moisture increases from intact to fully thawed permafrost stages, due to improved connections to the ground water (2007-2017 mean annual water table level $\pm$ standard deviation at partly thawed stage: $9.1 \pm$

115 4.6 cm below peat surface, fully thawed stage: 2.1 ± 4.4 cm above peat surface) (Crill et al., 2023; Holmes et al., 2022; Malhotra & Roulet, 2015). The peat depth reaches down to 3 m and is underlain by silt (Johansson et al., 2006).



120 **Figure 1: Location of the Stordalen mire and CH₄ flux and peat coring plots within the study area. Based on vegetation classification in 2014, the study area was classified into intact permafrost (tall shrub and hummock, in light blue), partly thawed permafrost (semi-wet and wet, in dark gray), fully thawed permafrost (tall graminoid, in dark blue), open water (bright blue) and other (rock and anthropogenic surfaces, in white) (Palace et al., 2018, 2022; Varner et al., 2022). Rectangles indicate automated chamber CH₄ flux measurement plots, circles indicate peat coring plots, and the cross represents the eddy covariance tower (ICOS: SE-Sto).**

2.2 Peat cores

We took peat cores using a push corer (d=12 cm, length=45 cm) to obtain plant material for belowground trait measurements. Despite destructive sampling being restricted, we were able to obtain three cores per thaw stage (n=9 cores in total). In addition, peat coring was not possible next to the CH₄ flux chambers and within the eddy covariance footprint, so we estimated the vegetation composition (vascular plant and moss species) in the chamber collars with vegetation surveys (point intercept method; Supplementary Methods A1, Table C1) and found representative vegetation patches for each chamber outside of the footprint. In the plot selection, emphasis was put on vascular plant species and secondarily on moss species cover. The peat

130 cores were collected on the 21st of July 2023. The tightly packed samples were put into a cooler with ice packs and stored frozen for four days. The samples were transported from Sweden to University of Zurich, Switzerland (11 h), and stored in a freezer in -20 °C until further processing.

2.3 Plant green area measurements

To compare the chamber and peat coring plots, and to provide a non-destructive aboveground plant trait comparison to the belowground traits, we estimated species-specific vascular plant green area (GA; Table 1 and C2). We randomly assigned three (peat coring plots) to five (chamber plots) subquadrats (16.8 x 16.8 cm) of the vegetation survey grid (Supplementary Methods A1) for GA measurements using the function sample in R (R Core Team, 2024). We measured green leaf and stem dimensions (leaf width and length, stem length and diameter) per species within each subquadrat. We measured 10 leaves per species per subquadrat, with the exception of fully thawed stage chamber plots where we measured all leaves and stems. For *E. nigrum*, we estimated the total number of leaves by counting all the leaves of three stems roughly representing the majority of the stems within the subquadrat. We calculated species-specific leaf and stem area (m²) based on geometric formulae, and GA was estimated based on the average number of green leaves and stems per m² multiplied by green leaf and stem area per m² (Wilson et al., 2007). Since the leaves of *Rubus chamaemorus* did not fit into a simple geometric formula, we estimated their green area using photos taken above the survey grid and ImageJ.JS v0.5.8 (Ouyang et al., 2019; Schneider et al., 2012) (see mean GA per species in Table C2).

Table 1: Vegetation characteristics at CH₄ flux chambers and corresponding peat coring plots at each permafrost thaw stage (intact, partly and fully thawed). “Core” refers to the plots where peat cores were taken for root and rhizome samples. “Species” includes the species encountered in the vegetation survey (Supplementary Methods A1), while vascular plant green area (GA) measurements

also included species that were not included in the plant cover measurements. “Total” in GA is the mean vascular plant GA across plots per thaw stage. See vegetation coverage at the plot level in Table C1.

Thaw stage	Species	Mean plant cover (%)		Mean GA (m ² m ⁻²)	
		Chamber	Core	Chamber	Core
Intact	<i>Eriophorum vaginatum</i>	66	41		
	<i>Andromeda polifolia</i>	31	27		
	<i>Vaccinium uliginosum</i>	25	24		
	<i>Empetrum nigrum</i>	17	31		
	<i>Rubus chamaemorus</i>	10	15		
	<i>Betula nana</i>	8	20		
	<i>Carex rotundata</i>	4	0		
	<i>Vaccinium vitis-idaea</i>	0	4		
	<i>Ptilium ciliare</i>	48	20		
	<i>Sphagnum balticum</i>	32	0		
	<i>Dicranum</i> sp.	8	27		
	<i>Polytrichum</i> sp.	0	20		
	Herbaceous	45	41	0.01	0.01
	Shrub	83	104	0.04	0.02
				Total: 1.98	Total: 3.61
Partly thawed	<i>C. rotundata</i>	48	48		
	<i>E. vaginatum</i>	0	42		
	<i>V. oxycoccus</i>	32	28		
	<i>A. polifolia</i>	28	24		
	<i>E. angustifolium</i>	0	16		
	<i>Drosera rotundifolia</i>	0	4		
	<i>S. capillifolium</i>	96	89		
	<i>P. ciliare</i>	0	16		
	Herbaceous	48	72	0.004	0.007
	Shrub	31	27	0.001	0.002
				Total: 0.05	Total: 0.09
Fully thawed	<i>E. angustifolium</i>	92	95		
	<i>Equisetum fluviatile</i>	32	44		
	<i>Comarum palustre</i>	4	12		
	<i>S. riparium</i>	26	96		
	Herbaceous	115	128	0.02	0.03
	Shrub	0	0	0.002	0
				Total: 0.32	Total: 0.8

2.4 Environmental variables

In order to compare the abiotic environmental characteristics of the peat coring plots with the chamber plots, we measured peat temperature (°C), pH, water table level (cm) and active layer depth (cm) at the individual plots (Table 2). Peat temperature

was measured 2-3 times a day (8 AM, 12 PM, 5 PM) at 10 cm depth over a three-day period (July 23rd-25th 2023) using a soil temperature probe (Testo 720, SN 03679207, Testo, Titisee-Neustadt, Germany). Active layer depth was measured with a metal rod.

We measured pH on July 25th 2023. For the intact and partly thawed plots, we took ca. 8.5 g of peat from 0.5 m distance from the chamber collar at ca. 5 cm depth (intact) or 7-10 cm depth (partly thawed). The pH was measured using a pH meter (826 pH mobile, SN 1826001012160, Metrohm, Herisau, Switzerland) and pH electrode (Polyplast, Ref 238380, SN13208, Hamilton, Reno, USA) by mixing the peat sample with CaCl₂ solution (10 ml 0.01 mol/L CaCl₂ per sample). At fully thawed plots, pH was measured directly from open water at ca. 5 cm depth. The electrode was always kept in liquid and when not in measurement solution, it was kept in a protective tube with KCl.

Half-hourly peat temperature data was measured with thermocouples installed at each chamber and acquired with CR10x data logger (Campbell Scientific Inc., UT, USA) (Bäckstrand et al., 2008; McCalley et al., 2014). As continuous soil moisture and water table level data were not available for the productive season in 2023, we used 10-year (2007-2017) water table depth (WTD) means and standard deviations per thaw stage from Crill et al., (2023) for a rough background estimate in soil moisture conditions. To estimate relationships between peat moisture and CH₄ fluxes, we also obtained soil moisture (volumetric water content, %VWC; Table C3) estimates for each chamber using soil moisture sensors (TMS-4 Standard, TOMST s.r.o., Prague, Czech Republic; Wild et al., 2019) at ca. 8 cm depth at ca. 1 m distance from the chambers. The soil moisture values were calibrated to peat using the myClim R package (Man et al., 2023; Wild et al., 2019). To obtain a representative estimate of the central tendency of the dominant peat moisture conditions at each chamber, we used overall chamber medians of daily-aggregated values (non-normal and distributions varied between chambers) from the May-August 2024 and 2025 periods.

180

Table 2: Peat characteristics at CH₄ flux chambers and peat coring plots per permafrost thaw stage (intact, partly and fully thawed).
“Core” refers to the plots where peat cores were taken for root and rhizome samples. See peat characteristics at the plot level in Table C1. ± denotes one standard deviation of the mean. Peat temperature was measured at 10 cm depth. WTD = water table depth (cm from peat surface), VWC = volumetric water content. Note that WTD for chamber plots is the mean annual WTD across the

2007-2017 period per thaw stage (Crill et al., 2023), and that peat moisture was estimated as overall chamber medians of the 2024-2025 period (see 2.4).

Thaw stage	Mean peat temperature (°C)		Mean pH		WTD (cm)		Mean active layer depth (cm)		Peat moisture (VWC; %)	
	Chamber	Core	Chamber	Core	Chamber	Core	Chamber	Core	Chamber	Core
Intact	8.6 ± 1.1	8.4 ±1.6	3.01	3.05	-	-	44.3	54	47.4 ± 11.2	-
Partly thawed	9.25 ± 0.6	9.6 ± 2.1	3.3	3.5	-9.1 ± 4.6	-20.9	>85	>85	76.9 ± 31.3	-
Fully thawed	9.05 ± 0.8	9.6 ± 2.1	4.9	5.5	2.1 ± 4.4	>0	>85	>85	100 ± 0	-

190

2.5 Root and rhizome trait quantification

We cut the frozen peat cores horizontally into minimum 10 cm increments, and then further into four vertical parts (ca. 25%) using a bandsaw. We randomly chose one of the quarters as a subsample for trait measurements. We thawed the subsamples in a refrigerator over 2-3 days and separated the aboveground vascular plants (see species-specific biomass in Table C4). We picked all living roots (light in color and elastic) and rhizomes (stiff, firm bark) from the subsample using tweezers and jeweler’s glasses (2.5x magnification). Due to the very high amount of shrub roots, we took a further subsample (ca. 15 g fresh weight) from which we picked all shrub roots. We cleaned the roots and rhizomes with deionized water and grouped them into herbaceous and shrub PFTs based on a combination of branching patterns, color, and thickness (e.g., shrub roots were generally thinner and had higher branching density than herbaceous roots). The forb *Rubus chamaemorus* was grouped into shrub PFT (e.g., Blume-Werry et al., 2019), due to root identification challenges. We did not separate coarse and fine roots but instead focused on the average root system properties. The picked roots were stored in 70% ethanol in a refrigerator (4 °C, max. 4 months).

We put the cleaned roots and rhizomes on a transparent tray filled with deionized water and scanned them with an Epson Perfection V700 Photo scanner (Epson, Japan), and analyzed them for root length, surface area and volume using WinRhizo Pro software (v. 2003b, Regent Instruments Inc., Québec, Canada). We used 1400 dpi for shrub roots with very fine roots (<1 mm), 600 dpi for herbaceous roots, and 100-300 dpi for rhizomes. When rhizome length and diameter were not accurately calculated by WinRhizo, we measured them manually using ImageJ.JS. Then, all roots and herbaceous rhizomes were dried in 70 °C and woody shrub rhizomes in 102 °C for 4 days and weighed at 0.00001 g precision to obtain root and rhizome dry

weight. To obtain a proxy of belowground gas transport potential (i.e., porosity), we calculated root and rhizome tissue density (TD, g cm^{-3}) by dividing their dry weight by fresh volume. For shrub rhizomes, the TD represents all the different rhizome tissues (e.g., bark, wood and pith). While this is not a direct measurement of the gas transport ability of a woody rhizome, low tissue density could indicate increased rhizome aeration (e.g., pith cavities) and possibly gas transport (Vroom et al., 2022). Specific root length (SRL, m g^{-1}) was calculated by dividing total root length by its dry weight.

Since peat core depths varied between plots, we standardized root total length (m m^{-2}), biomass (g m^{-2}) and surface area (SA, $\text{m}^2 \text{m}^{-2}$) to 30 cm depth by taking into account core volume and peat bulk density. We also standardized the traits to 10 cm depth for depth-specific analyses. In addition, shrub root and rhizome biomass, length and SA were scaled from the sub-subsample to the increment level and to 30 cm standardized depth. We calculated root and rhizome volumes by summing diameter-class-specific volumes from WinRhizo (Rose, 2017). All traits were calculated per PFT but also summed (biomass, length, and SA) or biomass-weighted (TD, SRL, diameter) to get an across-PFTs trait estimate. We used the rest of the peat core sample (remaining ca. 75%) to determine peat bulk density and gravimetric water content (GWC). We thawed the sample in a refrigerator over 2-3 days, removed the aboveground vascular plants, took a $5 \pm 0.2 \text{ g}$ subsample, and took its fresh and dry weight to obtain bulk density and GWC.

2.6 CH₄ flux measurements

CH₄ flux data were obtained from automated chambers (see data in Table C5). The details of the chamber measurement system in general are presented in Bäckstrand et al. (2008). In 2012, the chambers were replaced to similar design as in Bubier et al. (2003). In each thaw stage (intact, partly and fully thawed), three transparent automated gas flux chambers (basal area: 0.2 m^2 , height: 15-75 cm) measured CH₄ and CO₂ every three hours with 5-8 min enclosure time and 5 min air flushing before and after closure (Bäckstrand et al. 2008; Holmes et al. 2022). The CH₄ concentrations were measured with a Los Gatos Research Fast Greenhouse Gas Analyzer (Los Gatos Research Inc, Los Gatos, CA, USA) and the timing control and data acquisition was done with Campbell CR10x data logger (Campbell Scientific, Logan, UT, USA), which was located inside a temperature-controlled cabin. The CH₄ flux data were fit using linear regression. The data were quality-checked using regression diagnostics where CH₄ fluxes outside of significance thresholds at 95% and 90% confidence levels were filtered out (Snedecor and Cochran, 1989), as well as manual quality flags that were used to filter out data points affected by known instrumental issues.

We aggregated the higher frequency CH₄ flux data to daily scale by taking the daily CH₄ flux median. Median was chosen to estimate the central tendency of CH₄ fluxes due to skewed and non-normal flux data distributions, and to avoid the disproportionate influence of short-lived high CH₄ flux events that may not be related to belowground plant-mediated CH₄ cycling processes that were the main perspective of this study. Then, we subset the daily-aggregated chamber CH₄ flux data to contain the dates of the productive season in 2023. We defined the productive season as the period between the first and last passing of daily median net ecosystem CO₂ exchange (NEE) past zero, as this can be considered as the plant active season

relevant for plant-mediated CH₄ fluxes (Körner et al., 2023). For NEE, we utilized the half-hourly gap-filled NEE (NEE_VUT: estimated across 40 friction velocity threshold realizations for each year according to FLUXNET data processing protocols; quality flags=3 filtered out) from the ICOS Abisko-Stordalen Palsa Bog (SE-Sto) eddy covariance data processed with FLUXNET standards (Lundin et al., 2025; Pastorello et al., 2020). The resulting productive season used for CH₄ flux data subsetting was 2023-05-19 to 2023-08-30 (Fig. B1). As a background proxy for potential plant carbon substrate provision and plant-mediated gas transport (Knox et al., 2021), we also utilized the half-hourly gap-filled gross primary production (GPP; GPP_NT_VUT: nighttime partitioning at the daily scale and GPP_DT_VUT: daytime partitioning with light response curves at the hourly scale, with variable friction velocity thresholds implemented as an ensemble of 40 friction velocity thresholds by the FLUXNET team; see Lundin et al., 2025 and Pastorello et al., 2020 for details) data from Lundin et al. (2025). However, it is important to note that the EC tower footprint covers only intact and partly thawed stages and does not estimate the NEE and GPP for the fully thawed stage (Łakomiec et al., 2021). To explore the possible diurnal-scale plant-mediated CH₄ transport as a supporting analysis, we also aggregated CH₄ fluxes to the hourly scale using means and medians (Fig. B1).

To explore the variation in the trait-CH₄ flux relationships during the productive season, we calculated CH₄ flux period values (early, middle and peak CH₄ flux) by fitting Gaussian generalized additive models (GAM) with identity link function for daily median CH₄ flux data per chamber with function gam from package mgcv (Wood, 2011, 2017). In the models used for determining CH₄ flux period values, CH₄ flux (response variable) was transformed to approximate normality using inverse hyperbolic sine and date was included as an explanatory variable in a thin plate regression spline. Following an approach similar to TIMESAT (Eklundh & Jönsson, 2015; Jönsson & Eklundh, 2002) and Delwiche et al. (2021), CH₄ flux period values were calculated as follows: 1. peak CH₄ flux: the highest predicted CH₄ flux value during the productive season, 2. early CH₄ flux: the point where the predicted daily CH₄ flux reached 10% of the peak CH₄ flux for the first time, and 3. middle CH₄ flux: the point where the predicted daily CH₄ flux reached 50% of the peak CH₄ flux for the first time. We also calculated the whole season median to represent the whole productive season CH₄ flux estimate per chamber. Since one chamber at intact permafrost thaw stage had GAM R²<0.1, we used a moving 7-day median to estimate the early, middle and peak CH₄ season values. See details of GAM fit in Table C6.

2.7 Porewater CH₄ concentration and isotopic measurements

Data of porewater CH₄ and CO₂ concentrations, $\delta^{13}\text{CH}_4$ and $\delta^{13}\text{CO}_2$ were obtained from Wilson et al. (2026). The porewater samples were collected from the field near the automated flux chambers using stainless steel sippers on 25th and 26th of July 2023. The bottom of the sippers is perforated, and a syringe is attached to the top of the sipper via a stopcock. The sipper was inserted in the peat to the desired depth (0-4, 10-14, 20-24, 30-34, 40-44, 50-54, 60-64, 70-74, and 80-84 cm below peat surface) and the syringe was used to carefully draw up 30 mL of porewater. The porewater was then injected into pre-evacuated sealed glass serum vials. Phosphoric acid (1 mL, 10%) was added to each vial to preserve the samples and ensure that all dissolved inorganic carbon was in the form of dissolved CO₂ in equilibrium with gaseous CO₂. Porewater CO₂ and CH₄

concentrations and isotopes were analyzed simultaneously via headspace analysis, corrected for solubility using Henry's Law, on a Finnigan Mat Delta V Isotope Ratio Mass Spectrometer coupled to a gas chromatograph (Merritt et al., 1995). The analytical uncertainty based on repeated measurements of a standard was <0.15‰ for $\delta^{13}\text{CO}_2$ and $\delta^{13}\text{CH}_4$ and <5% for CO_2 and CH_4 concentrations. To obtain a robust estimate of the isotopic fractionation between CO_2 and CH_4 , we calculated the isotope fractionation factor (α_c) (e.g., Hodgkins et al., 2014; McCalley et al., 2014) with the following formula:

$$\alpha_c = \frac{\delta^{13}\text{CO}_2 + 1000}{\delta^{13}\text{CH}_4 + 1000} \quad (1)$$

2.8 Statistical analysis

To confirm the similarity of the peat core (n=9) and CH_4 flux plots (n=9), we used principal component analyses (function PCA from package FactoMineR; Lê et al., 2008), PERMANOVA (function adonis2 from package vegan; Oksanen et al., 2025), and Euclidean distances between plots within thaw stages, using normalized plot herbaceous and shrub plant cover and GA, mean peat temperature and pH (see Fig. B2).

For assessing general differences in daily median CH_4 flux between thaw stages across the productive season, we built linear mixed effects models where CH_4 flux was the response variable and thaw stage (factor) was the explanatory variable, and chamber (n=3 per thaw stage) was the random effect. To account for the normality of residuals and chamber-dependent temporal autocorrelation, we applied inverse hyperbolic sine transformation to CH_4 fluxes, and modeled temporal autocorrelation with autoregressive autocorrelation structure of order 1 (corAR1). We built three different models, where each had either intact, partly or fully thawed permafrost stage as the reference level and fit the model with restricted maximum likelihood and obtained p-values ($\alpha=0.05$) from Wald t-test. Linear mixed effects models were built with function lme from package nlme (Pinheiro & Bates, 2000; Pinheiro J, Bates D, R Core Team, 2023).

Due to the small sample size (n=3 per thaw stage), we were unable to test for statistical differences in belowground traits between thaw stages and sampling depths (traits, porewater CH_4 concentration and isotopic data) and relied on descriptive methods. However, to explore the general direction and strength of the relationships between root and rhizome traits and CH_4 fluxes (early, middle, peak, and season median) across the thaw stages, we used linear regressions with centered and scaled trait and CH_4 flux values. Only models which did not violate assumptions of homoscedasticity, linearity and normality of residuals were included in the analyses. In cases with little trait variation within each thaw stage, pseudoreplication was considered too severe for reliable model estimates, and these model results were not reported. We focused on model R^2 , slopes, and model p-values. In cases where linear regressions were unreliable or violated the model assumptions, we explored the relationship strength with Kendall τ correlation coefficients. We acknowledge that the model and correlation estimates can be unstable with small sample size and thus use them as descriptive exploratory tools for estimating the changes in the general directions of the trait- CH_4 flux relationships across thaw stages during the productive season. All data processing and statistical analyses were conducted in R v4.5.1 (R Core Team, 2025).

3 Results

3.1 More herbaceous roots with decreasing tissue density

Belowground traits varied between thaw stages, and the biomass-weighted traits followed shifts from shrub- to herbaceous-
dominated plant communities (Fig. 2, Table C1). Summed root biomass and surface area (SA) were 22.2x and 17.0x lower,
respectively, at the fully thawed than intact stage, but herbaceous root biomass (mean: $238.3 \pm 172 \text{ g m}^{-2}$) and SA (mean: $19.9 \pm 13 \text{ m}^2 \text{ m}^{-2}$) were highest at partly thawed stage. Total shrub root length reached a very high mean of 178.62 km m^{-2} and a maximum of 199.7 km m^{-2} in the intact stage, substantially higher values than for herbaceous roots (mean: 19.79 km m^{-2} and max 33.33 km m^{-2} in the partly thawed stage) (Fig. B4). While shrub rhizome biomass and SA decreased from intact to partly thawed stage, herbaceous rhizomes showed an opposite trend (e.g., mean SA $0.13 \pm 0 \text{ m}^2 \text{ m}^{-2}$ to $3.41 \pm 0.08 \text{ m}^2 \text{ m}^{-2}$, 26-fold increase). Notably, herbaceous root and rhizome tissue density (TD) were 1.5x and 2.4x lower in fully thawed than in intact permafrost, respectively (mean $\pm$ standard deviation root $0.004 \pm 0.0008 \text{ g cm}^{-3}$ to $0.003 \pm 0.0002 \text{ g cm}^{-3}$; rhizome $0.2 \text{ g cm}^{-3} \pm 0$ to $0.08 \pm 0.01 \text{ g cm}^{-3}$), and these decreases were reflected in the biomass-weighted values (root: 1.5x lower, rhizome: 7.4x lower). While specific root length (SRL) was highest at partly thawed stage (mean shrub $193.6 \pm 32 \text{ m g}^{-1}$, 1.4x higher than at intact; mean herbaceous $71.6 \pm 35 \text{ m g}^{-1}$, 2.3x and 1.2x higher than at intact and fully thawed, respectively), the biomass-weighted means showed a 2.2-fold decrease from intact to fully thawed stage.

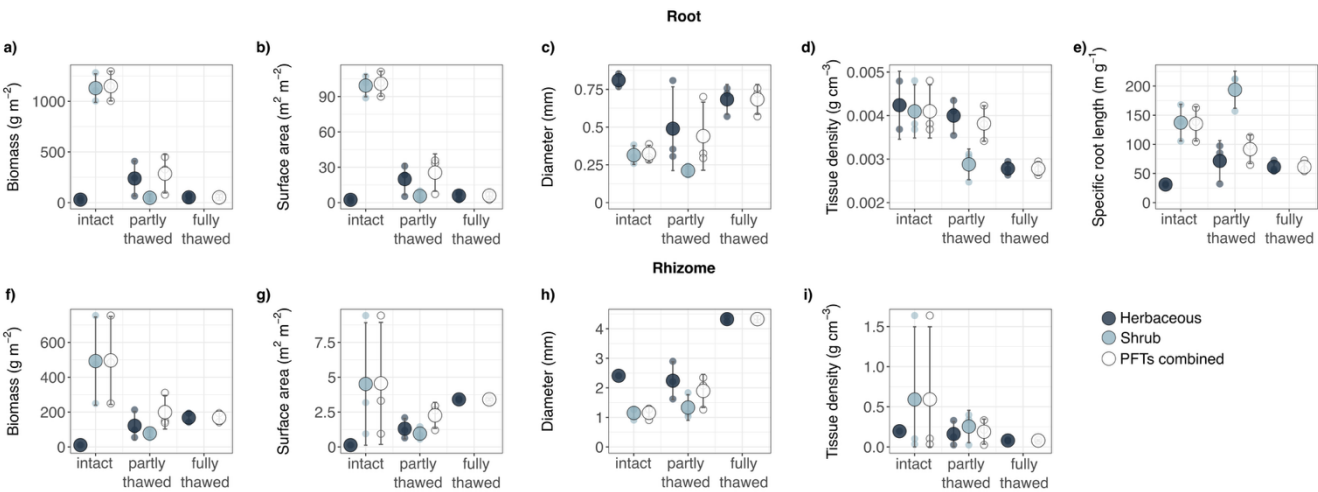


Figure 2: Belowground traits varied between thaw stages. Root traits (a-e) are shown in the top row and rhizome traits (f-i) in the
bottom row. Large points represent group means, small points plot-scale measurements, and error bars ± 1 standard deviation of
the mean. The colors represent plant functional types (PFT; dark grey: herbaceous, light grey: shrub, white: PFTs combined). Trait
values for combined PFTs were summed herbaceous and shrub values (a, b, f, and g) or biomass-weighted means between
herbaceous and shrub PFTs (c-e, h and i).

Most of the root biomass was found in the top 10 cm for shrub (coefficient of variation CV and mean for intact: 69%, $766.0 \pm 155 \text{ g m}^{-2}$; partly thawed: 67%, $65.1 \pm 28 \text{ g m}^{-2}$) and herbaceous PFTs (CV and mean intact: 56%, $17.5 \pm 9 \text{ g m}^{-2}$, partly thawed: 45%, $86.4 \pm 89 \text{ g m}^{-2}$, fully thawed: 73%, $27.7 \pm 20 \text{ g m}^{-2}$) (Fig. B3). Shrub roots reached the maximum total length of 167.3 km m^{-2} at top 10 cm at the intact stage (Fig. B4). SRL and root TD varied less with depth across thaw stages (max CV SRL: 51%, TD: 31%; partly thawed herbaceous). All herbaceous rhizomes were present in the top 10 cm (mean biomass intact: $11.5 \pm 0 \text{ g m}^{-2}$, partly thawed: $101.9 \pm 109 \text{ g m}^{-2}$, fully thawed: $107.8 \pm 12 \text{ g m}^{-2}$, Fig. B5). Most of the shrub rhizomes were located in the top 10 cm (CV and mean biomass intact: 78.5%, $392.4 \pm 227 \text{ g m}^{-2}$; partly thawed: 66.7%, $93.9 \pm 15 \text{ g m}^{-2}$), but they were also found in 10-20 cm depth (mean intact: $109.4 \pm 154 \text{ g m}^{-2}$, partly thawed: $28.9 \pm 0 \text{ g m}^{-2}$).

3.2 Root tissue density, specific root length and diameter correlated best with CH₄ fluxes

The relationships between root traits and CH₄ fluxes (CH₄ flux difference between intact, partly and fully thawed $p < 0.01$, fully and partly thawed $p > 0.05$, Supplementary Methods A2) differed between PFTs but with little temporal variation. Increasing root TD was associated with decreasing CH₄ flux for herbaceous (min standardized regression beta coefficient, β at peak CH₄, max β at middle CH₄) and shrub PFTs (min β at middle CH₄, max β at CH₄ season median) (Fig. 3). Shrub root diameter had negative (min β at early CH₄, max β at CH₄ season median) and SRL positive (min β at peak CH₄, max β at CH₄ season median) associations with CH₄ fluxes. In general, the direction and strength of the relationships between root traits and CH₄ fluxes did not vary strongly across CH₄ flux season values (Fig. 3, B6).

PFTs combined, all root traits except diameter showed negative trends, where the strongest relationships were for root TD (min β at early and peak CH₄, max β at middle CH₄) (Fig. 3). In addition, summed root biomass and SA showed relatively strong negative relationships, with biomass showing slightly stronger negative relationships than SA (biomass: min Kendall's τ at early CH₄, max τ at middle CH₄; SA: min τ at early CH₄, max τ at peak CH₄) (Fig. B6).

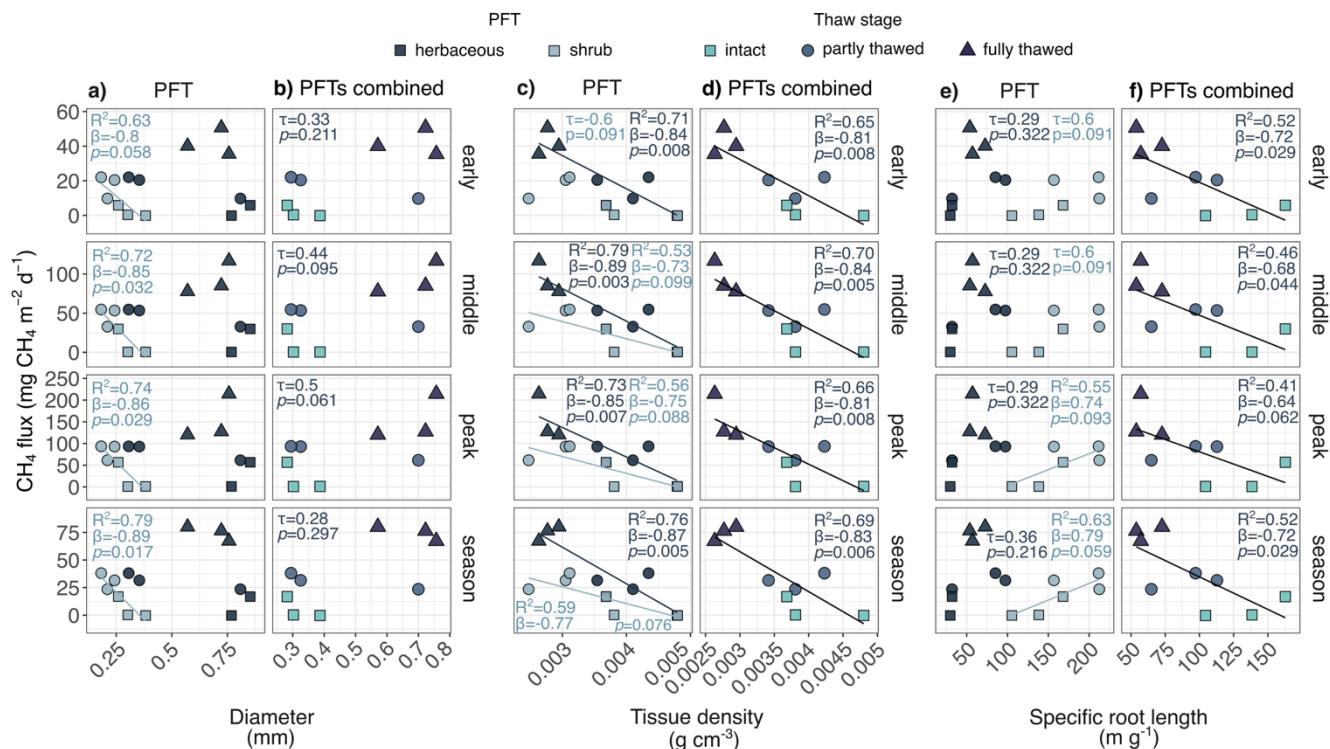


Figure 3: Root tissue density, diameter, and specific length showed strongest relationships with CH₄ fluxes. a-b) Relationships between root diameter and CH₄ fluxes (early, middle, peak and season) per plant functional type (PFT; a) and across PFTs (biomass-weighted means; b). c-d) Relationships between root tissue density and CH₄ fluxes per PFT (c) and across PFTs (biomass-weighted means; d). e-f) Relationships between specific root length and CH₄ fluxes per PFT (e) and across PFTs (biomass-weighted means; f). In a, c and e, dark gray: herbaceous plants, light gray: shrubs. In b, d and f, light blue rectangle: intact, grey circle: partly thawed, dark purple triangle: fully thawed stage. In all plots (a-f), lines represent linear regression for visualization, while R² and standardized effect size/slope (β) are based on linear regressions with centered and scaled trait and CH₄ flux values (lines, R² and β are only shown when R²>0.2, model p<0.1, and the linear regression model assumptions were met). Kendall's τ is shown for relationships where linear regression model assumptions were not met and τ≥0.2 (note that due to the low sample size, p-values should be interpreted with caution). See relationships between root biomass, surface area and CH₄ fluxes in Fig. B6.

Herbaceous and shrub rhizome traits showed contrasting relationships with CH₄ fluxes (Fig. 4, B7). Herbaceous rhizome biomass and SA showed positive relationships with CH₄ fluxes, with stronger trends for SA (SA: min β at peak CH₄, max β at CH₄ season median). Increases in herbaceous rhizome diameter were also associated with slightly higher CH₄ fluxes (min τ at early to peak CH₄, max τ at CH₄ season median). In contrast, shrubs had negative trends between rhizome biomass and CH₄ fluxes (min τ at early, middle and season median CH₄, max τ at peak CH₄; Fig. B7). While summed rhizome SA did not show clear trends (Fig. 4), higher summed rhizome biomass was associated with lower CH₄ fluxes (nonsignificant β at early CH₄,

max β at peak CH₄; Fig. B7), while the relationship between rhizome diameter and CH₄ flux was positive (min τ at early and middle CH₄, max τ at peak and season median CH₄) (Fig. 4).

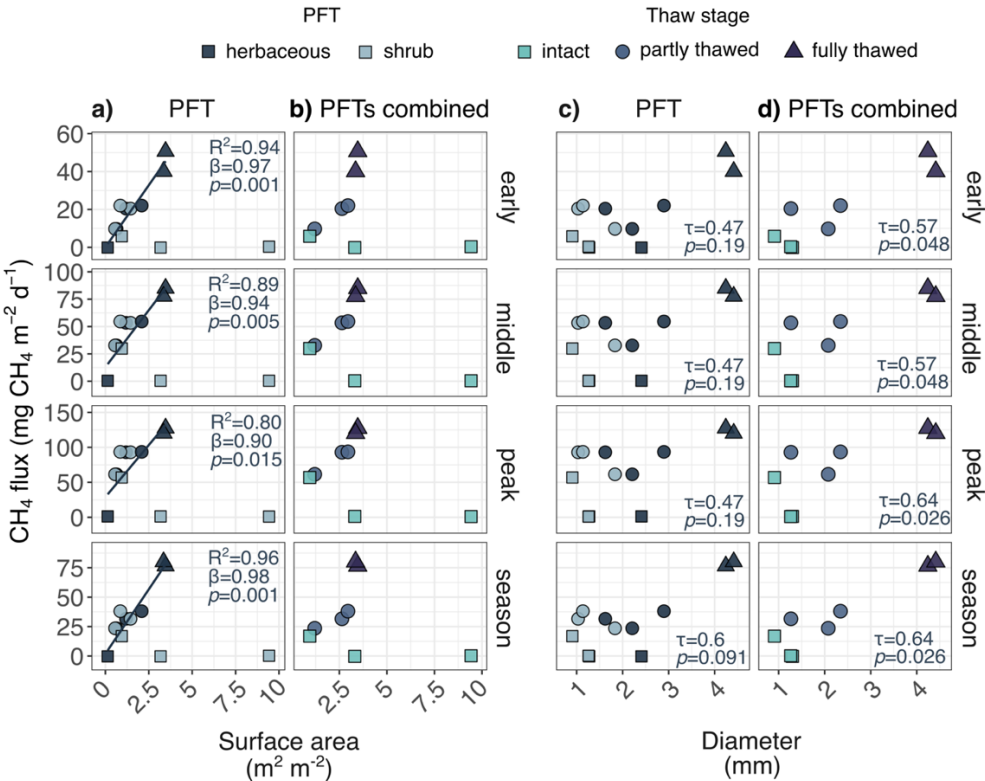


Figure 4: Relationships between rhizome traits and CH₄ fluxes were strongest for surface area and diameter. Columns a-b) Relationships between rhizome surface area and CH₄ fluxes (early, middle, peak and season; rows) per plant functional type (PFT; a) and across PFTs (summed; b). Columns c-d) Relationships between rhizome diameter and CH₄ fluxes per PFT (c) and across PFTs (biomass-weighted means; d). In a and c, dark gray color represents herbaceous plants while light gray represents shrubs. In b and d, light blue rectangles represent the intact permafrost, dark blue circles represent the partly thawed stage, and dark purple triangles represent the fully thawed stage. Lines represent linear regressions for visualization, while R^2 and standardized effect size/slope (β) are based on linear regressions with centered and scaled trait and CH₄ flux values (lines, R^2 and β are only shown when $R^2 > 0.2$, model $p < 0.1$, and the linear regression model assumptions were met). Kendall's τ is shown for relationships where linear regression model assumptions were not met and $\tau > 0.2$. See relationships between rhizome biomass, tissue density and CH₄ fluxes in Fig. B7.

In comparison with belowground trait relationships, CH₄ fluxes were weakly and positively correlated with plant green area (GA) and peat temperature (Fig. B8). GA, which also did not show clear trends with permafrost thaw (Fig. B9), showed no clear relationships with CH₄ fluxes (max τ for shrub at peak CH₄; Fig. B8). Peat temperature did not show clear relationships with CH₄ fluxes (max τ at middle CH₄; Fig. B8). However, increases in peat moisture were generally associated with higher

385 CH₄ fluxes ($\tau=0.73$ at early, middle and season median CH₄; Fig. B8), with the highest CH₄ fluxes occurring in the wettest plots in the fully thawed stage (median VWC=100%), and lowest CH₄ fluxes in the drier intact stage (median VWC=43.4%).

4 Discussion

Permafrost thaw in subarctic peatlands can lead to substantial alterations in peatland hydrology, vegetation composition and carbon cycling, and higher CH₄ emissions with higher water table level and more anoxic conditions belowground (Johnston et al., 2014; Knoblauch et al., 2018; Turetsky et al., 2014; Varner et al., 2022). These trends were visible in the Stordalen Mire where CH₄ fluxes increased significantly from intact to fully thawed permafrost stage with maximum CH₄ fluxes in August (Supplementary Methods A2 and Fig. B10), and porewater CH₄ concentrations increased with depth and CH₄ production slightly shifted from hydrogenotrophic to acetoclastic methanogenesis (Fig. B11), as has been observed previously at Stordalen (Hodgkins et al., 2014; Holmes et al., 2022; McCalley et al., 2014; Perryman et al., 2020; Varner et al., 2022). Shifts from hydrogenotrophic to acetoclastic methanogenesis can indicate increased root exudate-driven CH₄ production (see 4.2) (Saarnio et al., 2004; Ström et al., 2003).

The increased CH₄ fluxes with permafrost thaw in Stordalen are driven by a complex network consisting of drivers such as higher water table level and increased anoxia (Holmes et al., 2022; Malhotra & Roulet, 2015), higher peat temperatures at the end of growing season (Mollenkopf et al., 2026), increased labile carbon availability (Hodgkins et al., 2014; Holmes et al., 2022; Hough et al., 2022), shifts in microbial communities from hydrogenotrophic to acetoclastic methanogens (McCalley et al., 2014), and increasing dominance and productivity of graminoid vegetation (Christensen et al., 2004; Johansson et al., 2006; Malhotra & Roulet, 2015; Öquist & Svensson, 2002; Varner et al., 2022). For the first time in Stordalen and, to our knowledge, in other thawing permafrost peatlands, we explored the effect of belowground plant traits on CH₄ fluxes. In general, root and rhizome traits reflected plant community transitions and were consistent with an increase in plant-mediated transport of acetoclastically-produced CH₄.

4.1 Root and rhizome traits reflect plant community shifts along permafrost thaw gradient

The vegetation composition in Stordalen follows the changing hydrology and soil nutrient availability. The vegetation shifts from shrub-dominated (intact stage; e.g., *R. chamaemorus*, *B. nana*, and *E. nigrum*) palsas to increasingly more graminoid- and *Sphagnum*-dominated semi-wet bogs (partly thawed; e.g., *V. oxycoccos*, *C. rotundata*, and *S. capillifolium*) and wet fens (fully thawed; *E. angustifolium*, *E. fluviatile*, and *S. riparium*; Table C1 and C2) (Hough et al., 2022; Johansson et al., 2006; Malhotra & Roulet, 2015; Varner et al., 2022). Following these vegetation transitions, plant traits reflect plant adaptation to the changing environmental conditions (Dong et al., 2020; Moor et al., 2017; Pan et al., 2019). While studying plant trait variation and its influence on ecosystem functioning often requires species-specificity to capture changes in diversity (Kichenin et al., 2013; Violle et al., 2014) and separation into fine and coarse root fractions (Freschet et al., 2021b; McCormack et al.,

2015), CH₄ flux models often utilize PFTs which have been found to adequately represent the collective trait effects on CH₄ fluxes in peatlands (Gray et al., 2013; Laine et al., 2022). Thus, we here focused on root and rhizome traits at the PFT (herbaceous and shrub) level. This approach provides empirical constraints on plant-mediated carbon substrate provision and CH₄ transport that can inform parameterization and sensitivity analyses in process-based wetland CH₄ models, such as LPJ-GUESS (Smith et al., 2001, 2014), and HIMMELI (Raivonen et al., 2017).

Following vegetation community shifts, most belowground shrub biomass and total length were found in the intact stage while herbaceous biomass increased from intact to fully thawed stage. The shrub root biomass values were lower than previous estimates for *R. chamaemorus*, *E. nigrum* and *A. polifolia* (total >2000 g m⁻²) in Stordalen (Wallén, 1986), but are much higher than recent belowground biomass estimates (~280 g m⁻²; Hough et al., 2022). In addition, Hough et al. (2022) reported higher total root biomass at the fully thawed (~218 g m⁻²) than partly thawed stage (~146 g m⁻²), whereas this study showed the opposite (Fig. 2). These differences could arise from different root biomass standardization and sampling methods, a problem highlighted in root ecology (Freschet et al., 2021a): Wallén (1986) calculated fine root biomass based on ¹⁴C activity which can lead to overestimations (Wallén, 1986), while Hough et al. (2022) sampled a larger area (625 cm²) than in our study (~79 cm²), leading to differences particularly at the fully thawed stage, where graminoids root more vertically than laterally. In addition, our root samples may have consisted of a different mix of species than in Hough et al. (2022), which together with the low sample size, may have influenced these results. Nonetheless, root biomass decreased by depth, as is common particularly for shrubs (Iversen et al., 2015; Wallén, 1986). As we observed *R. chamaemorus* roots up to 30 cm depth, similar to Wallén (1986) and Keuper et al. (2017) in Stordalen and by Metsävaio (1931) in Finnish peatlands, and as *E. angustifolium* and *E. fluviatile* roots have been found at 40 cm depth (Iversen et al., 2015; Metsävaio, 1931; Shaver & Billings, 1975), the maximum rooting may occur deeper than our sampling depth (ca. 30 cm). In general, these findings, and particularly the remarkably high total shrub root length values, showed that permafrost-affected peat soils are rich in plant roots and likely contribute to the carbon cycling of these ecosystems (Bardgett et al., 2014; Iversen et al., 2015).

Variation in tissue density (TD) and specific root length (SRL) (Fig. 2) with thaw suggest changes in plant gas transport and resource acquisition. Increasing soil moisture with thaw (via higher water table level; Table 2 and Fig. B8) and subsequent aerenchyma formation (e.g., Jackson & Armstrong, 1999) may have decreased TD. The increase in herbaceous rhizome SA may reflect greater aerenchyma proportion, confirming rhizome SA as a proxy for plant gas transport capacity. SRL was highest and root diameter lowest at the partly thawed stage, which could reflect increased resource acquisition particularly for shrubs (Bergmann et al., 2020), but further research with larger sample sizes is needed to investigate the potential changes in shrub resource acquisition. As the peat C/N ratio is highest in the partly thawed stage (Hodgkins et al., 2014), the high SRL may reflect low N availability, shifts in species and species-specific resource acquisition (Hewitt et al., 2019; Keuper et al., 2017). However, as fine root SRL is more meaningful for resource acquisition (Bergmann et al., 2020; McCormack et al., 2015), our results based on the whole root system provide only a rough estimate. Nonetheless, 99% of total shrub root length

450 was <2 mm in diameter (vs. 31%, 75%, and 63% in intact to fully thawed stages, respectively, for herbaceous), and thus within the traditional fine root definition (McCormack et al., 2015).

4.2 Belowground traits reflect increasing plant-mediated CH₄ transport

The increasing peat moisture and associated changes in belowground plant traits contributed to the increasing CH₄ fluxes along the permafrost thaw gradient. Given our exploratory results (see 3.2 and Fig. B8) and earlier studies conducted at Stordalen
455 (Holmes et al., 2022; Malhotra and Roulet, 2015), the increasing peat moisture was likely one of the primary drivers of the increasing CH₄ fluxes along the thaw gradient. However, due to the low sample size we were unable to separate the effects of plant traits and peat moisture in multivariate models, and larger sample sizes are recommended to analyze the interactions between peat moisture and plant belowground traits in future studies. Nonetheless, the univariate relationships between plant belowground traits and CH₄ fluxes indicated 1) maintained carbon substrate provision and 2) increasing plant-mediated CH₄
460 transport across the permafrost thaw gradient. In Stordalen, permafrost thaw has led to increasing plant-derived labile carbon availability and acetoclastic methanogenesis (Hodgkins et al., 2014; Holmes et al., 2022; McCalley et al., 2014; Ström & Christensen, 2007), but plant-mediated CH₄ transport has so far been mostly assumed based on literature and plant aboveground characteristics and activity, such as number of shoots and gross photosynthetic rates (Öquist & Svensson, 2002).

465 Shrub roots suggested increasing carbon substrate provision. The higher CH₄ fluxes with increasing shrub SRL (and smaller diameter; Bergmann et al., 2020) may be related to increased root exudation (Guyonnet et al., 2018; Wen et al., 2022). The negative root TD-CH₄ flux relationships support this, as higher root TD may be associated with lower root exudation (Wen et al., 2022). In contrast, herbaceous SRL was weakly associated with CH₄ fluxes, possibly due to decoupling of root exudation and SRL in some Cyperaceae species in nutrient-limited environments (Wen et al., 2022), and the SRL also including coarse
470 roots (Picon-Cochard et al., 2012). However, based on the ¹³C-depleted $\delta^{13}\text{CH}_4$ and high α_c , hydrogenotrophic methanogenesis may have dominated in the topmost peat, and most of the dissolved, less bioavailable organic carbon possibly originated from *Sphagnum* in the partly thawed stage (Hodgkins et al., 2014; McCalley et al., 2014; Mondav et al., 2014; Wilson et al., 2022). Nonetheless, the lower α_c , more enriched $\delta^{13}\text{CH}_4$, and higher CH₄ concentrations below the root sampling depth (30-44 cm) indicated acetoclastic methanogenesis (Fig. B11) (e.g., by *Methanosarcina*; McCalley et al., 2014), possibly fueled by root
475 exudates (Saarnio et al., 2004; Ström et al., 2003; Ström & Christensen, 2007). Indeed, based on photosynthetic rates, the partly thawed stage has been estimated to have more labile carbon for methanogenesis (Öquist & Svensson, 2002), and *E. angustifolium* and *E. vaginatum* have high potential root exudation rates in Stordalen (Ström & Christensen, 2007) and graminoid root exudation rates can exceed that of shrubs in the partly and fully thawed stages (Mollenkopf et al., 2026). Based on these previous studies, it is possible that the SRL based on the whole heterogeneous root system did not represent the
480 potential root exudation accurately for herbaceous plants. Thus, roots (including herbaceous) may have exuded labile carbon, but with shrubs having a lesser effect on the net CH₄ flux.

Herbaceous plant coverage increased with thaw, which was reflected in traits indicating plant-mediated CH₄ transport (Fig. 2, Table C1). Higher herbaceous rhizome SA was positively associated with greater CH₄ fluxes, which, together with the positive diameter-CH₄ flux trends, could indicate enhanced CH₄ transport via larger and more porous rhizomes (Määttä & Malhotra, 2024). Rhizome-mediated CH₄ transport could be particularly relevant for plants with pressurized gas transport, such as *Equisetum* spp., where pressure gradients between the atmosphere, leaves, and rhizomes can drive CH₄ emission via old leaves and broken stems (Vroom et al., 2022). As shrub rhizomes were not associated with CH₄ fluxes (Fig. 4, B8), they may not drive plant-mediated CH₄ cycling in Stordalen, though standardized measurements of, e.g., rhizome length and biomass are needed to confirm this (e.g., Freschet et al., 2021a).

Plant-mediated CH₄ transport may have been pronounced in the fully thawed stage with high peat moisture, herbaceous plant coverage, and low porewater CH₄ concentrations (Table C1 and Fig. B8, B11), indicating plant CH₄ uptake. As low root and rhizome TD indicates higher porosity (Ye & Ryser, 2022), the negative relationships between root TD and CH₄ flux suggest increased plant-mediated CH₄ transport in response to increasing peat moisture. The isotopic evidence (heavier $\delta^{13}\text{CH}_4$ and lower α_c) may further suggest plant-mediated transport of acetoclastically-produced CH₄ at the fully thawed stage (Chanton, 2005). This supports previous findings of higher herbaceous shoot numbers increasing CH₄ flux in the fully thawed stage (Öquist & Svensson, 2002). However, a recent study conducted in the same productive season found that 30% of the CH₄ flux in the fully thawed stage consisted of graminoid plant-mediated CH₄ transport and the rest of CH₄ production stimulated by graminoid root exudation, while in the partly thawed stage plant-mediated CH₄ transport dominated the CH₄ flux (80%) (Mollenkopf et al., 2026). Nonetheless, both this and the study by Mollenkopf et al. (2026) together suggest increased herbaceous plant-mediated CH₄ transport and carbon substrate provision in the fully thawed stage. In Stordalen, most of the plant-mediated CH₄ transport likely occurs via diffusion, typical for *Carex* spp., *E. angustifolium*, and *E. vaginatum* (e.g., Ge et al., 2025; Noyce et al., 2014; Bhullar et al., 2013). CH₄ diffusion may be more efficient through *E. angustifolium* with low root branching in the fully thawed than at partly thawed stage with more densely rooted *Carex* species (Schimel 1995; Shaver & Billings, 1975; Table C1). However, pressurized CH₄ transport via *Equisetum fluviatile* (in fully thawed stage) could be negligible and requires further investigation as we did not separate the belowground material into species (Hyvönen et al., 1998; Kankaala & Bergström, 2004). As graminoid (e.g., *E. angustifolium*) roots have low bioavailability in the fully thawed stage (Hough et al., 2022), and root porosity and decomposability may be decoupled (Pan et al., 2019; Ye & Ryser, 2022), the low root and rhizome TD were unlikely to lead to increased decomposition and carbon substrate provision.

Simultaneously to plant-mediated CH₄ transport, herbaceous roots may have enhanced rhizospheric CH₄ oxidation. Previous studies at Stordalen have reported shifts in methanotroph communities with thaw as well as an increase in CH₄ consumption, which may result from greater plant-mediated rhizospheric oxidation (i.e., more O₂ transport with lower root TD) and acetoclastic methanogenesis (Perryman et al., 2020; Singleton et al., 2018). In addition, *Sphagnum* spp. can host methanotrophic CH₄-consuming bacteria (e.g., Larmola et al., 2010; Putkinen et al., 2014), which may have increased CH₄

consumption in the more O₂-rich intact and partly thawed stages dominated by *S. balticum* and *S. capillifolium*, with intact stage chambers possibly having higher CH₄ consumption rates than peat cores with no *S. balticum* (Table 1). However, the average $\delta^{13}\text{CH}_4$ emitted from the partly thawed chamber plots was $-79.6 \pm 0.9 \text{ ‰}$ in 2011, similar to or ¹³C-depleted relative to the porewater CH₄ at the same sites, indicating little CH₄ oxidation (McCalley et al., 2014). Thus, the heavier $\delta^{13}\text{CH}_4$ in the fully and partly thawed stages could also indicate increased CH₄ oxidation close to O₂-rich air at the topmost peat or in the oxidized rhizosphere at ca. 20-44 cm depth (Perryman et al., 2020; Singleton et al., 2018). In addition, during CH₄ oxidation, methanotrophs preferentially consume lighter ¹²CH₄, enriching the remaining CH₄ pool in ¹³C while producing isotopically light CO₂ (Whiticar, 1999). However, isotopically light CO₂ could also indicate less methanogenesis instead of increased methanotrophy, and rhizospheric $\delta^{13}\text{CH}_4$ enrichment can also result from faster plant ¹²CH₄ uptake and increased plant-mediated CH₄ transport (Chanton, 2005). Thus, based on the lower α_c (i.e., maintained acetoclastic methanogenesis) at 20-44 cm depth, and the strongly negative relationships between root TD and CH₄ fluxes (i.e., decreasing amount of aerenchyma is related with lower CH₄ fluxes and vice versa), it seems that the CH₄-oxidizing effect of herbaceous plants particularly in the fully thawed stage is overshadowed by increased carbon provision for methanogenesis and enhanced plant-mediated CH₄ transport.

4.3 Belowground trait relationships with CH₄ fluxes did not vary within the productive season

The relationships between the static belowground traits and CH₄ fluxes (early, middle, peak, and season median) did not vary strongly within the productive season. This may result from the lack of temporal root and rhizome sampling within the productive season. However, as an exploratory analysis, our results may indicate higher herbaceous plant-mediated CH₄ transport at the middle CH₄ flux period (Fig. 3). In contrast to our hypotheses, shrub root traits were more strongly related (i.e., higher linear regression β and R^2) with peak and season median CH₄ fluxes whereas herbaceous root (TD) and rhizome (SA) traits were strongly related with CH₄ fluxes throughout the season. This could result from the lack of temporal sampling, but also from low temporal variation in coarse root diameter (diameter is used for determining root TD; see 2.5) (Picon-Cochard et al., 2012), possibly contributing to the lack of temporal trends between root diameter and CH₄ fluxes. The root TD-CH₄ flux relationships may have reflected higher CH₄-transporting herbaceous root biomass at the middle and peak CH₄ flux period (July-September; Shaver & Billings, 1977) instead of temporal TD and diameter variation. Indeed, diffusive plant-mediated CH₄ transport via *Carex* spp. could be high during the mid- and peak-growing season, as for example *Carex rostrata* (present at the partly and fully thawed stages but not captured by our aboveground measurements; see Table C1 and e.g., Hough et al., 2022) has been found to transport most CH₄ at high summer and early autumn (Ge et al., 2025; Noyce et al., 2014). Furthermore, a study conducted in Stordalen during the same productive season found that plant-mediated CH₄ transport and carbon substrate provision via graminoids was highest in August and September, further confirming these results (Mollenkopf et al., 2026). In addition, gross primary production (GPP), a proxy for plant-mediated gas transport (Knox et al., 2021), peaked in July and August (max monthly medians: 3.87 and 2.79 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$, respectively; Fig. B1). Concurrently, CH₄ fluxes at the partly and fully thawed stages were slightly higher during nighttime (Fig. B1). Both of these GPP and CH₄ flux trends

could further indicate seasonally (via higher herbaceous plant biomass) and diurnally- (via stomatal opening and closure) varying plant-mediated CH₄ transport . However, as GPP and CH₄ flux peaks did not coincide in the same hourly time periods, further research into diel CH₄ fluxes and plant-mediated CH₄ transport is needed (Fig. B1) (Knox et al., 2021). As *Carex*, *Eriophorum* and *Equisetum* rhizomes are perennial (Husby, 2013; Shaver, 1976), the pre-existing rhizomes may have contributed to CH₄ transport particularly in the beginning of the productive season with active root growth (esp. *E. angustifolium*; Shaver & Billings, 1975), resulting in strong rhizome-CH₄ flux relationships (Fig. 4, B7).

Our exploratory analyses suggested stronger shrub carbon substrate provision (SRL and diameter) at peak CH₄ flux period and across the season (season median; Fig. 3). While uncertain due to the static trait values, these results could be supported by the greater GPP at the intact and partly thawed stages (Łakomiec et al., 2021) in July and August (Fig. B1), as GPP can also be a proxy for root exudation and correlates with increased wetland CH₄ emissions (Knox et al., 2021). In addition, in a separate study within the same productive season, shrubs and graminoids were found to release more root-derived carbon at the end of the season (Mollenkopf et al., 2026). However, the biomass-weighted SRL trends were negative, which could result from species-specific SRL variation and the heterogeneous herbaceous root system (Gao et al., 2024; Picon-Cochard et al., 2011). The stronger negative trends in the beginning of the productive season may arise from increased plant carbon investment into herbaceous root growth in comparison with shrubs (Billings et al., 1978; Kummerow & Russell, 1980; Wang et al., 2016). However, within the intact and partly thawed stages and in a mixture of herbaceous and shrub plants, the SRL-CH₄ flux trends could in fact be positive (Fig. 3), but inferential statistics with larger sample sizes per thaw stage are required to investigate this further. As temporal variation in SRL and its relationship with root exudation can be negligible throughout growing season (Gao et al., 2024) and studies in (sub)arctic peatlands are lacking (Iversen et al., 2015), the negative trends between biomass-weighted SRL and CH₄ fluxes across the thaw gradient remain uncertain.

Taken together, the temporal variation in root and rhizome traits may have contributed to CH₄ fluxes but belowground trait sampling with larger sample sizes throughout the productive season is needed to investigate these relationships further. Given the uncertain herbaceous SRL and root diameter relationships, future studies could benefit from separating the roots into coarse and fine fractions, measuring the associated root exudation rates, and utilizing minirhizotrons (Iversen et al., 2012; Phillips et al., 2008) to disentangle the temporal variation in root carbon substrate provision and CH₄ transport across the permafrost thaw gradient.

5 Conclusions

Permafrost thaw alters peatland methane (CH₄) fluxes through changes in soil anoxia, nutrient and labile carbon availability, and vegetation composition. Here, we explored the relationships between plant root and rhizome traits and CH₄ fluxes along a permafrost thaw gradient in a subarctic peatland. The belowground traits reflected vegetation community shifts along the

thaw gradient from shrub- to herbaceous-dominated, with decreasing shrub belowground biomass and root tissue density with increasing thaw. Root tissue density showed a strong negative correlation with CH_4 fluxes, and increasing herbaceous rhizome surface area was associated with higher CH_4 fluxes. These relationships indicated increasing plant-mediated CH_4 transport with thaw, which was supported by lower pore water CH_4 concentrations in the fully thawed stage. Simultaneously, shrub specific root length (SRL) was positively, and root diameter negatively related with CH_4 fluxes, suggesting increased labile carbon substrate provision for acetoclastic methanogenesis. The relationships did not vary strongly during the productive season, but this was likely a result of the static belowground trait data, warranting further temporal trait sampling.

We encourage further observational and experimental research particularly into the relationships between root and rhizome tissue density, SRL and CH_4 fluxes. The observed relationships could be further investigated with larger sample sizes and by combining temporal root trait sampling, root separation into fine and coarse fractions, and root exudation measurements to especially quantify the relationship between SRL and root exudation. Nonetheless, as root and rhizome trait data are scarce particularly from permafrost peatlands, and as the contribution of roots and rhizomes on plant-mediated CH_4 fluxes is understudied, this study provided valuable belowground proxies for plant-mediated CH_4 transport and fluxes. These proxies can inform future observational and experimental studies, as well as process-based wetland models by improving parameterization particularly related to plant-mediated CH_4 transport and helping fill gaps in our understanding of plant-mediated CH_4 cycling.

6 Appendices

600 Appendix A: Texts

Supplementary Methods A1: Vegetation surveys

To evaluate the similarity between the CH_4 flux chamber plots and peat core plots, we conducted vegetation surveys using the point-intercept method on July 19th-23rd 2023. We used a 1.01 m² survey grid divided into 36 subquadrats (16.8 cm x 16.8 cm = 0.03 m²) and 25 intercept points. We lowered a dowel (60 cm long, 0.5 cm diameter) at each intercept point and noted the presence (i.e., “hit”) of each vascular plant and moss species that the dowel touched. At the peat core plots, the grid was always positioned towards northeast from the measurer and with the core in the middle of the grid. At the chamber plots, the grid was positioned so that the chamber collar was approximately in the middle of the northeast edge of the grid (due to the chamber structure, we were unable to set the collar perfectly in the middle of the grid). The ground cover (e.g., litter and water), plant and moss species were surveyed separately. For ground cover data, if the measuring dowel hit multiple classes, only the class that touched the dowel first was recorded. Species and ground cover percentages were obtained by dividing the sum of hits for a species, vegetation (herbaceous, shrub and moss) or ground cover class by the total number of intercepts (n=25), multiplied by 100.

Supplementary Methods A2: Chamber CH₄ flux analyses

615 The fully thawed permafrost stage had the highest CH₄ flux (season median=75.2 mg CH₄ m⁻² d⁻¹, IQR=60.6 mg CH₄ m⁻² d⁻¹), followed by partly thawed stage (season median=30.0 mg CH₄ m⁻² d⁻¹, IQR=33.6 mg CH₄ m⁻² d⁻¹) but CH₄ fluxes at partly and fully thawed stages did not differ significantly (p>0.05). Intact stage had the lowest CH₄ fluxes (season median=0.3 mg CH₄ m⁻² d⁻¹, IQR=2.1 mg CH₄ m⁻² d⁻¹, p<0.01). At all thaw stages, CH₄ flux increased from the beginning to the end of the productive season: the maximum monthly median CH₄ fluxes were observed in August (max CH₄ flux: fully thawed 375.9 mg CH₄ m⁻² d⁻¹, partly thawed 160.4 mg CH₄ m⁻² d⁻¹, intact 96.4 mg CH₄ m⁻² d⁻¹), while minima were reached in June at intact (-1.9 mg CH₄ m⁻² d⁻¹) and fully thawed (10.3 mg CH₄ m⁻² d⁻¹) stages, and in May at the partly thawed stage (2.0 mg CH₄ m⁻² d⁻¹). In general, variation in CH₄ flux (coefficient of variation, CV) was larger between thaw stages (94%; May: 109%, August: 79%) than within them but the intact stage had large within-stage CH₄ flux variation (148%) which increased from May and June (125% and 124%, respectively) to August (165%), while the other stages had relatively low variation (partly thawed: 37%, fully thawed: 29%).

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Appendix B: Figures

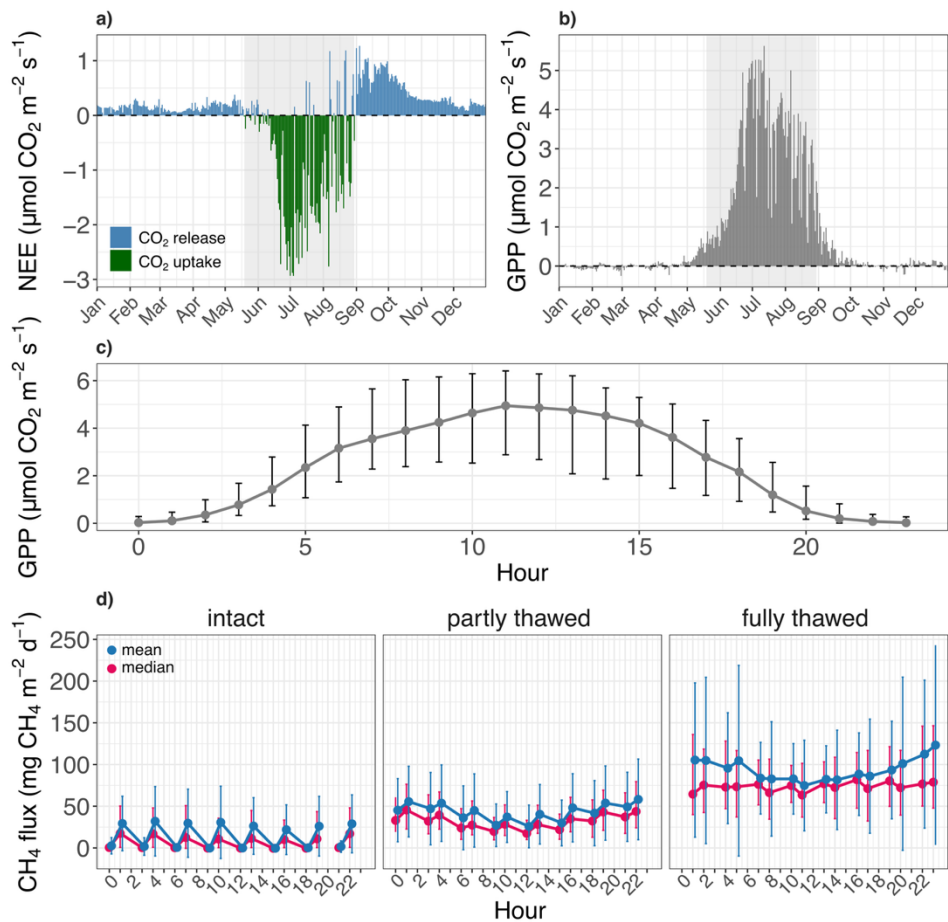


Figure B1: Daily net ecosystem CO₂ exchange (NEE; $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) (a) and gross primary production (GPP; $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) (b), and hourly GPP and CH₄ fluxes during the productive season in 2023. a) The productive season was defined as the period between the first and last passing of daily median NEE past zero (highlighted in gray; 19th of May 2023 to 30th of August 2023) (Körner et al., 2023). b) Daily median GPP (based on nighttime partitioning) is shown for reference as a proxy for plant-mediated carbon substrate provision at the ecosystem scale (Knox et al., 2021). c) Hourly GPP medians (based on daytime partitioning with light response curves for better estimation of diurnal trends). The error bars represent the ranges between 25th and 75th percentiles around the hourly medians. d) Hourly CH₄ flux medians (in red) and means (in blue) at each permafrost thaw stage. The error bars represent the ranges between 25th and 75th percentiles around the hourly medians. Hourly means are shown in addition to medians to reflect short-term CH₄ pulses at the diurnal scale. NEE and GPP data: Lundin et al., 2025. Note that the NEE and GPP data likely mostly originate from intact and partly thawed permafrost stages and do not cover the fully thawed stage (Łakomiec et al., 2021).

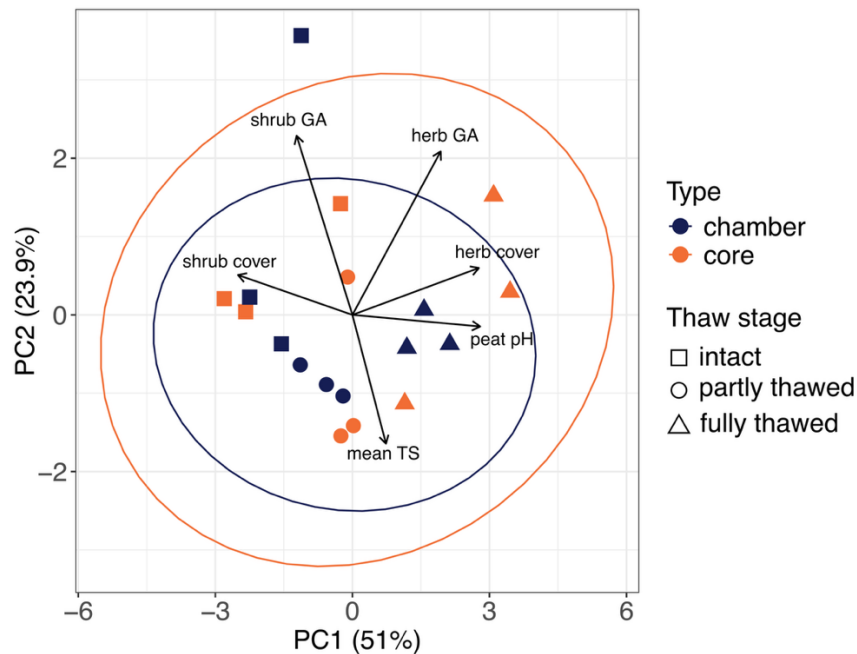


Figure B2: The similarity of peat core (n=9) and automated chamber CH₄ flux measurement (n=9) plots based on principal component analysis (PCA). In the figure, chamber and core plots are represented by dark purple and orange points, respectively, while thaw stages are shown in different shapes (rectangle = intact permafrost, circle = partly thawed permafrost, triangle = fully thawed permafrost). The ellipses represent 95% data ellipses for the chamber and core plots within the multivariate space defined by the first two principal components (chamber = dark purple, orange = core). The PCA was based on normalized plot herbaceous and shrub plant cover and green area (GA), mean peat temperature (mean TS) and peat or porewater pH (here, referred to as peat pH), using function PCA from package FactoMineR (Lê et al., 2008) (results shown in the figure). In addition, we used PERMANOVA with function adonis2 from package vegan (Oksanen et al., 2025) and Euclidean distances between plots within thaw stages to estimate the similarity between core and chamber plots based on the same environmental variables. Based on these assessments, the peat core plots had a larger spread in multivariate space than CH₄ flux plots mostly due to slightly higher shrub or herbaceous plant cover in one plot within each thaw stage, but the differences were not significant with the sample size n=9 (p=0.94). Thus, the root and rhizome measurements could be used to roughly represent belowground traits in the CH₄ flux measurement plots. However, we acknowledge that the measured root and rhizome traits do not exactly correspond to those within the CH₄ flux plots and took this into account in the result interpretation.

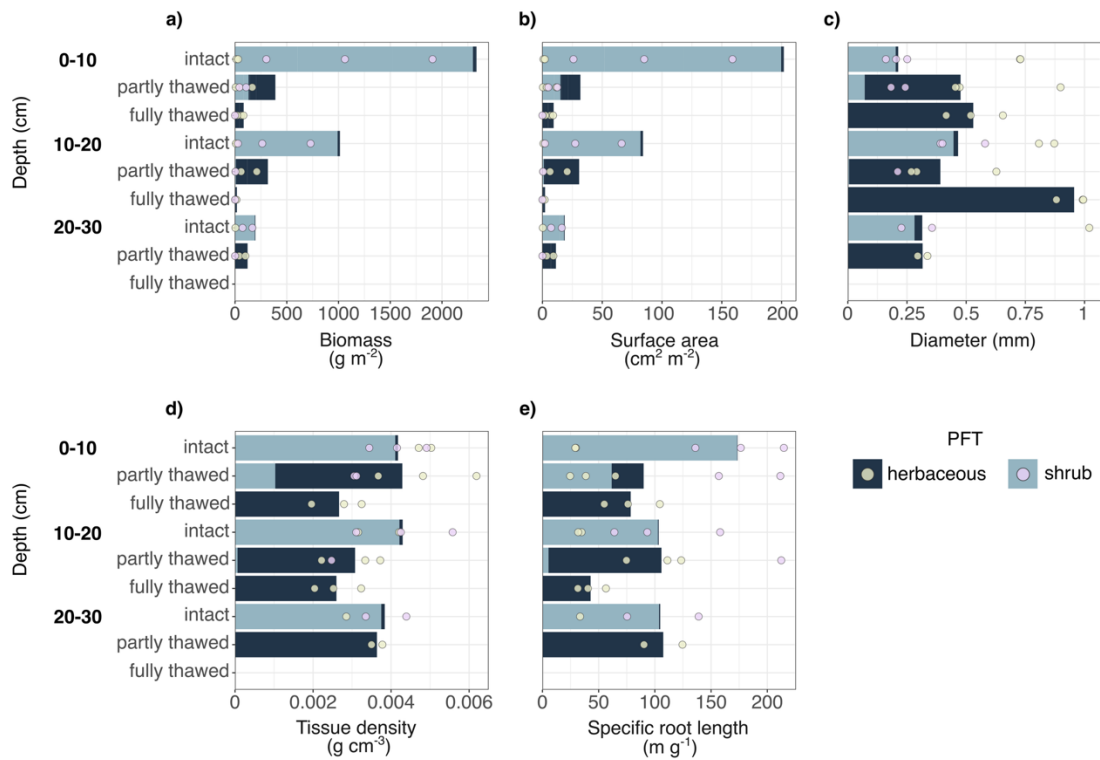
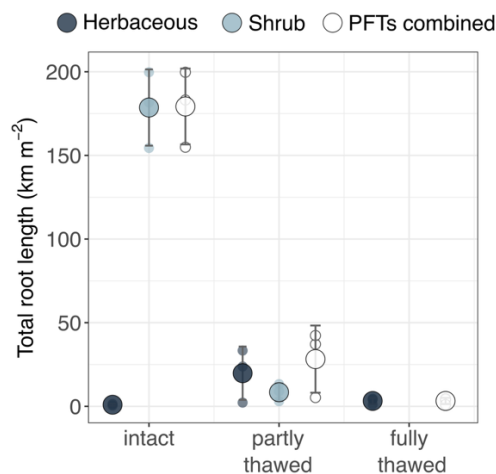
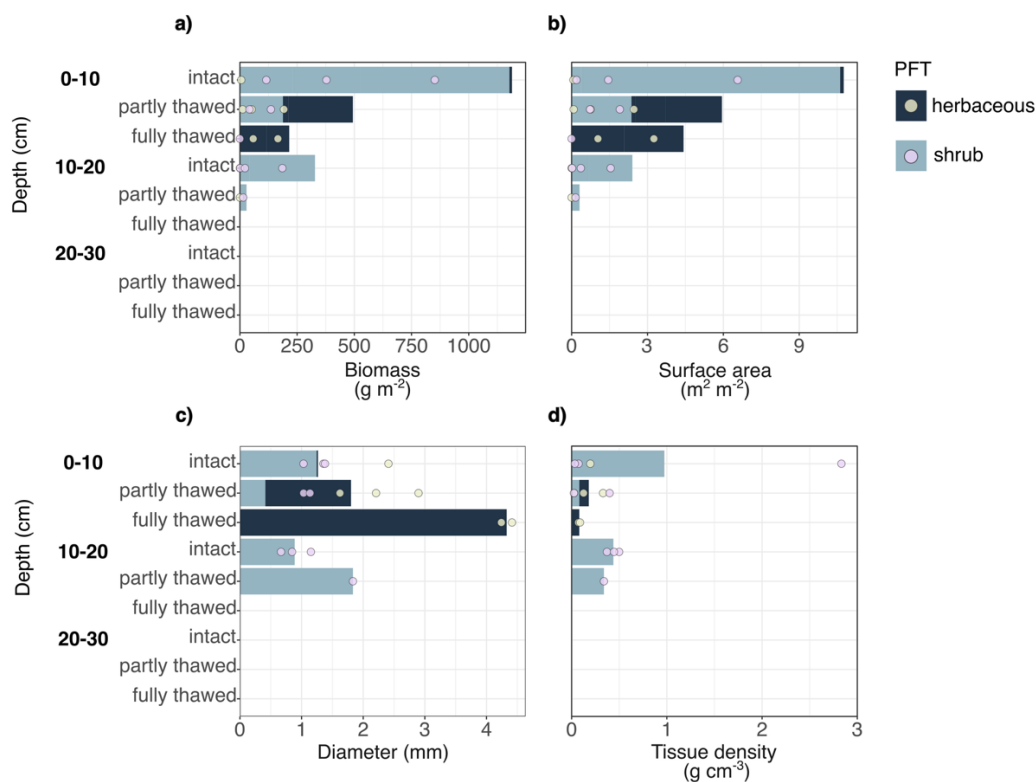


Figure B3: Root traits across the depth profile (0-10, 10-20, 20-30 cm) per thaw stage and plant functional type (PFT). The stacked bar colors (dark blue: herbaceous, light blue: shrub) represent the proportion of the PFT on the total biomass (a) or surface area (b), or the contribution of each PFT on the biomass-weighted trait mean (c-e). The points (light green: herbaceous, light purple: shrub) represent depth-per-plot measurements. a-b) and e) Root biomass, surface area and length were standardized to 10 cm depth increments. c)-e) Biomass-weighted trait means.



660 **Figure B4: Root total length (km m^{-2}) across thaw stages per and across plant functional types (PFT). Large points indicate thaw stage mean and small points plot-scale measurements. Colors indicate PFTs (dark grey: herbaceous, light grey: shrub, white: PFTs summed). Error bars represent 1 standard deviation of the mean. Root total length was standardized to 30 cm depth in all plots.**



665 **Figure B5: Rhizome traits across the depth profile (0-10, 10-20, 20-30 cm) per thaw stage and plant functional type (PFT). The stacked bar colors (dark blue: herbaceous, light blue: shrub) represent the proportion of the PFT on the total biomass (a) or surface**

area (b), or the contribution of each PFT on the biomass-weighted trait mean (c-d). The points (light green: herbaceous, light purple: shrub) represent depth-per-plot measurements. a-b) and e) Root biomass, surface area and length were standardized to 10 cm depth increments. c-d) Biomass-weighted trait means.

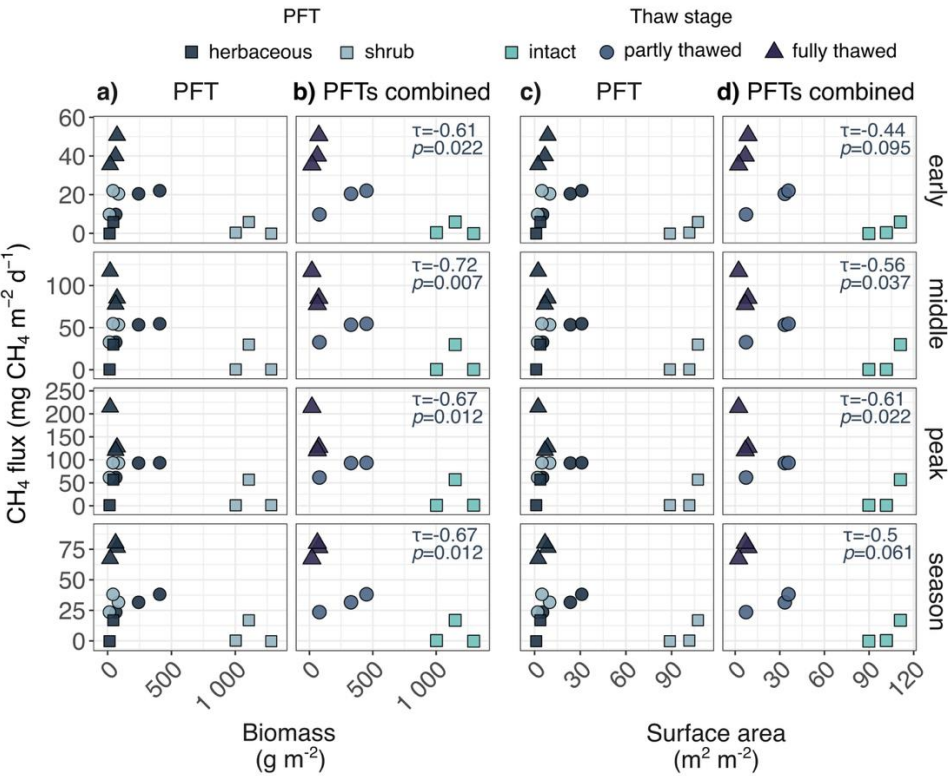


Figure B6: Relationship between root biomass (columns a-b), surface area (columns c-d) and CH₄ fluxes (early, middle, peak and season; rows). a and c) Relationships between root traits and CH₄ fluxes per plant functional type (PFT), where dark gray: herbaceous plants, light gray: shrubs. B and d) Relationships between root traits and CH₄ fluxes across PFTs (biomass and surface area summed), where light blue rectangle: intact, gray circle: partly thawed, and dark purple triangle: fully thawed stage. Kendall's τ is shown for relationships where $\tau \geq 0.2$ (note that due to the low sample size, p-values should be interpreted with caution). Linear regression model assumptions were not met for any of the relationships.

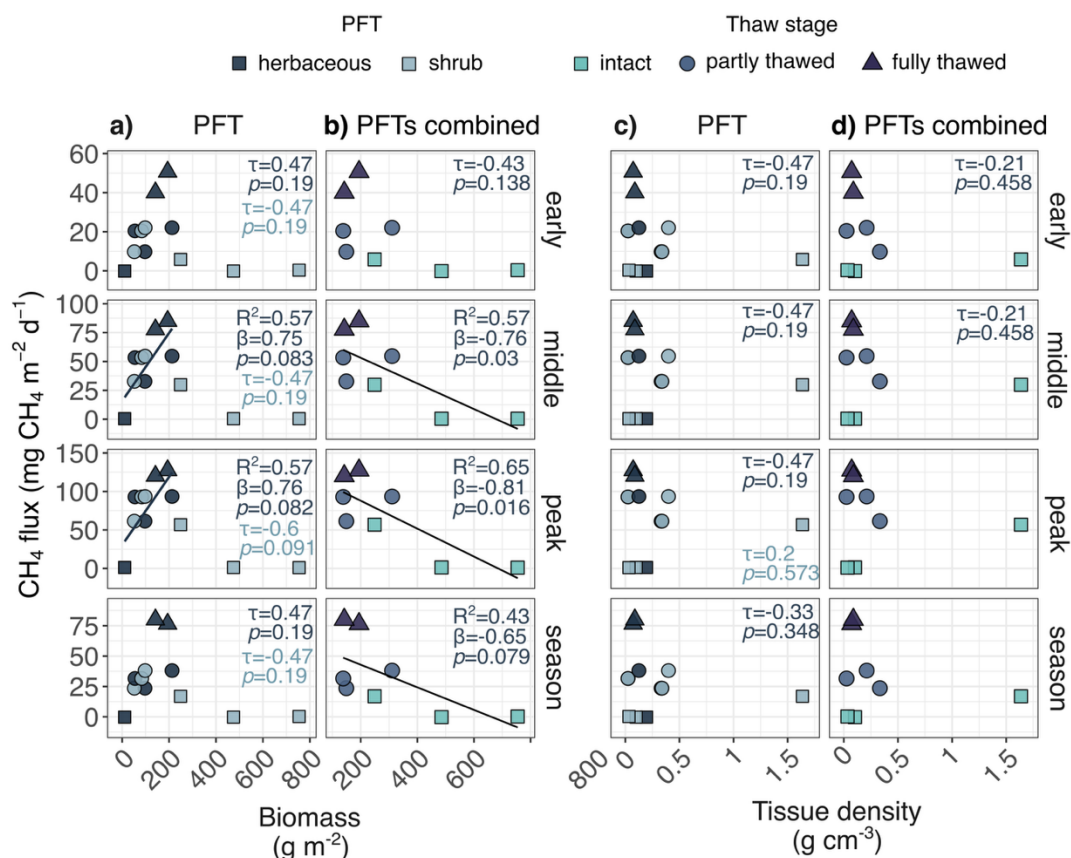


Figure B7: Relationship between rhizome biomass (columns a-b), tissue density (columns c-d) and CH₄ fluxes (early, middle, peak and season; rows). a and c) Relationships between rhizome traits and CH₄ fluxes per plant functional type (PFT), where dark gray: herbaceous plants, light gray: shrubs. b and d) Relationships between rhizome traits and CH₄ fluxes across PFTs (summed biomass, biomass-weighted tissue density), where light blue rectangle: intact, gray circle: partly thawed, and dark purple triangle: fully thawed stage. The lines represent linear regression fit used for visualization, while R² and effect size (β) are reported for linear regressions with centered and scaled CH₄ flux and trait values (when R²>0.2, model p<0.1, and linear regression model assumptions were met). Kendall's τ is shown for relationships where τ≥0.2 (note that due to the low sample size, p-values should be interpreted with caution).

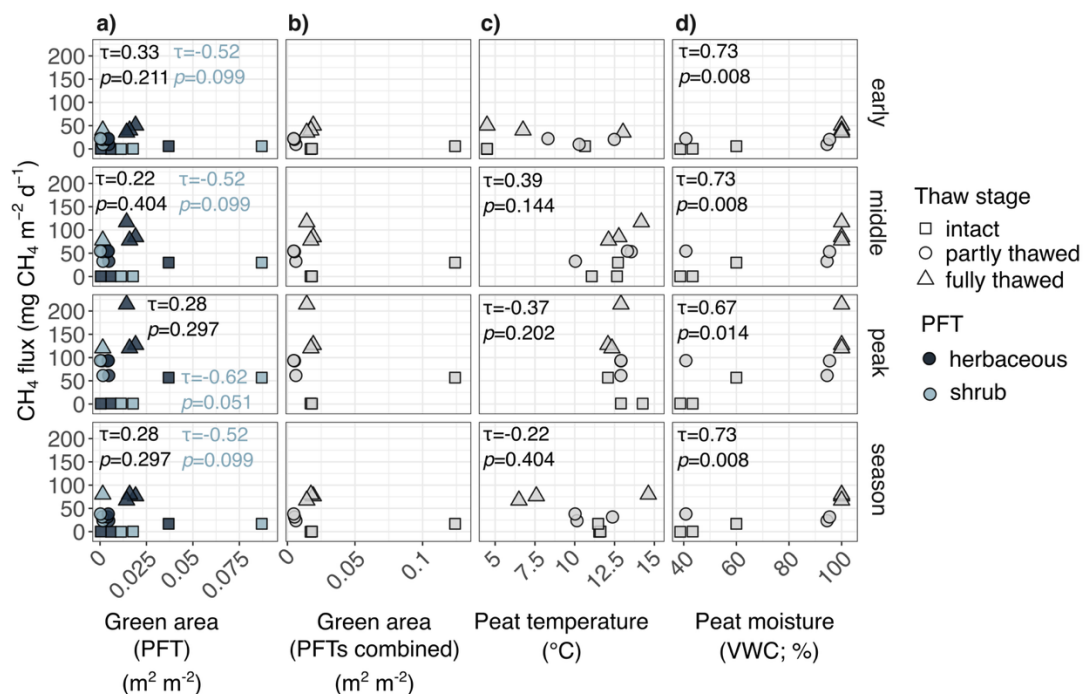
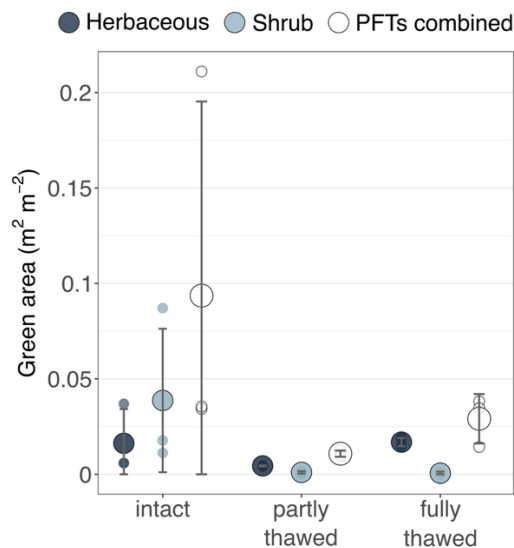
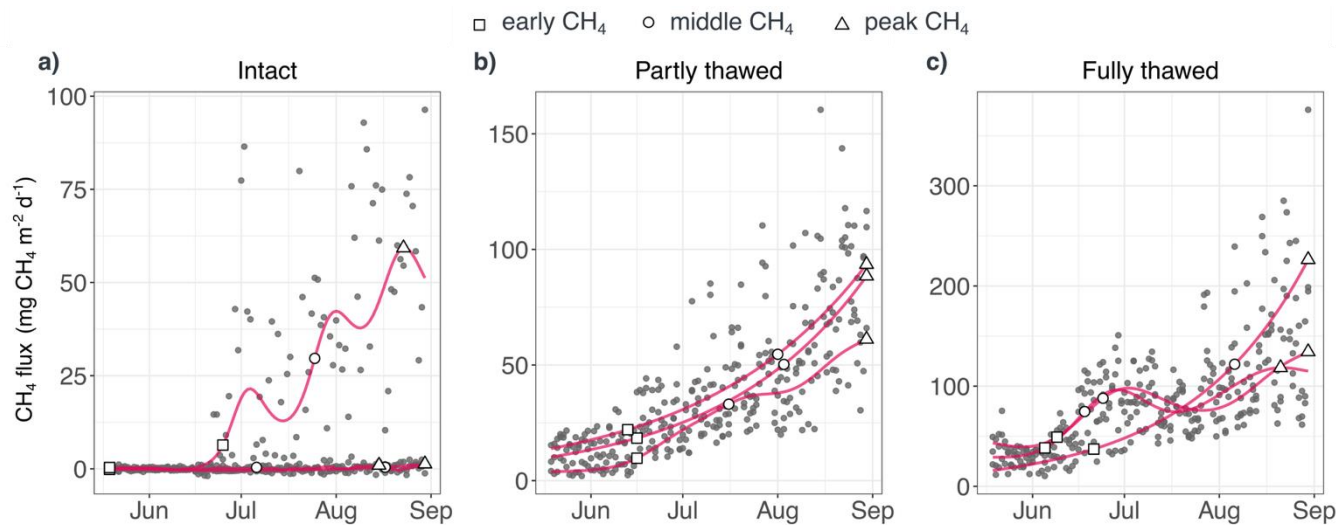


Figure B8: Relationship between plant functional type (PFT)-specific plant green area (column a), plant green area summed across PFTs (column b), peat temperature (column c), peat moisture (volumetric water content VWC; column d), and CH_4 flux season values (rows). Kendall τ correlation coefficient (τ) is reported for the relationship when $\tau > 0.2$ (note that due to sample $n=9$, the correlation p-values should be interpreted with caution). The different point shapes represent thaw stages (rectangle = intact permafrost, circle = partly thawed permafrost, and triangle = fully thawed permafrost). a) Colors represent different PFTs (dark blue = herbaceous plants, light blue = shrubs).



695 **Figure B9: The plant green area (GA; $\text{m}^2 \text{m}^{-2}$) varied slightly between thaw stages. Large points represent group means, small points plot-scale measurements, and error bars ± 1 standard deviation. The colors represent plant functional type (PFT) groups: dark grey is herbaceous, light grey is shrub, and white is the sum of PFT GAs. Herbaceous GA coefficient of variation (CV) was highest within intact permafrost (137%), while shrub GA varied most within intact permafrost (109%). Note that shrubs (*Betula nana*) were only found in one plot and were only 3% of the total GA in the fully thawed permafrost stage.**



700 **Figure B10: Daily median CH_4 flux with CH_4 flux period values over the productive season at intact (a), partly thawed (b) and fully thawed (c) stages. a-c) Red lines represent chamber-specific GAM fit ($R^2 \geq 0.3$), except for one chamber in a) where $\text{GAM } R^2 < 0.1$, and the line represents the moving 7-day median CH_4 flux. Squares represent early, circles middle and triangles peak CH_4 flux season. See chamber GAM R^2 in Table C5.**

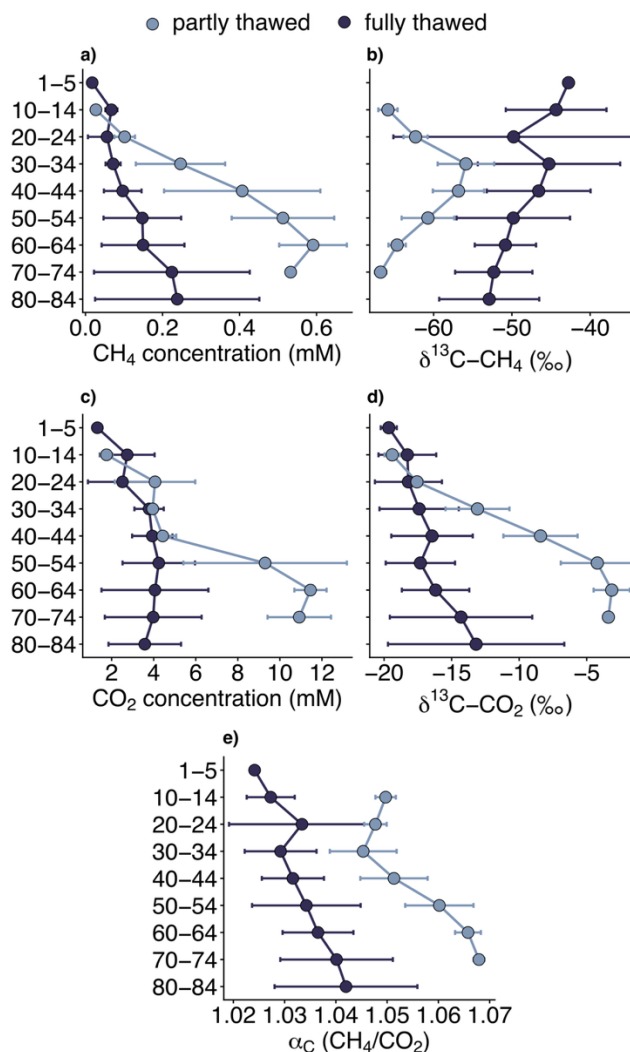


Figure B11: Porewater CH₄ concentration (mM) (a), δ¹³C-CH₄ (‰) (b), CO₂ concentration (c), δ¹³C-CO₂ (‰) (d), and carbon isotope fractionation factor (α_C CO₂/CH₄) (e) from peat surface to 84 cm depth at partly and fully thawed permafrost stages. Line and point colors represent thaw stages. c) α_C : higher values indicate larger fractionation (i.e., more hydrogenotrophy) and vice versa (i.e., more acetoclasty). Briefly, mean CH₄ concentrations increased from 0.027 ± 0.004 (standard deviation) mM to 0.533 ± 0.0007 mM at 70-74 cm depth at the partly thawed stage and from 0.017 ± 0.007 mM to 0.238 ± 0.213 mM at 80-84 cm depth at the fully thawed stage. δ¹³C-CH₄ values became enriched at ca. 30-44 cm (partly thawed ca. -56.4 ‰, fully thawed ca. -46 ‰), and this enrichment was associated with a decrease in α_C (ca. 1.048 partly thawed, ca. 1.03 fully thawed). Mean CO₂ concentrations increased from 1.758 ± 0.284 mM to 11.454 ± 0.766 mM at 60-64 cm depth and 10.923 ± 1.51 at 70-74 cm depth at the partly thawed stage (with a decrease at 30-44 cm depth, with means of 3.951 and 4.430 mM), and from 1.322 ± 0.089 mM to 3.576 ± 1.725 mM at 80-84 cm at the fully thawed stage. δ¹³C-CO₂ became more enriched with depth particularly at the partly thawed stage (from -19.398 ‰ to -3.394 ‰).

Appendix C: Tables

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Table C1: Plant cover (%) by species and herbaceous and shrub vegetation classes, litter and water surface cover (%), and peat characteristics in each chamber and peat coring (“core”) plot (as peat cores were selected to represent each individual chamber, the core and chamber plots have the same ID number). Note that the intact 1 chamber plot was on a collapsing palsa. Chamber plot WTD is the mean annual WTD across the 2007-2017 period per thaw stage (Crill et al., 2023). Values after “±” are one standard deviation of the mean. WTD = water table depth (cm; from the peat surface).

Plot	Species	Plant cover (%)		Litter and water cover (%)		Mean soil temp (°C)		pH		WTD (cm)		Active layer depth (cm)	
		Chamber	Core	Chamber	Core	Chamber	Core	Chamber	Core	Chamber	Core	Chamber	Core
Intact 1	<i>Eriophorum vaginatum</i>	48	28	Litter: 20	Litter: 16	9.5 ± 0.9	9.3 ± 1.5	3.1	3.0	-	-	47	37.5
	<i>Vaccinium uliginosum</i>	48	28										
	<i>Andromeda polifolia</i>	32	24	Water: 0	Water: 0								
	<i>Empetrum nigrum</i>	24	56										
	<i>Rubus chamaemorus</i>	0	8										
	<i>Vaccinium vitis-idaea</i>	0	4										
	<i>Dicranum</i> sp.	8	52										
	<i>Polytrichum</i> sp.	4	0										
	Shrub	104	120										
	Herbaceous	48	28										
Intact 2	<i>A. polifolia</i>	52	48	Litter: 28	Litter: 16	7.7 ± 0.6	7.7 ± 1.1	3.1	3.0	-	-	41.5	39
	<i>E. nigrum</i>	16	16										
	<i>R. chamaemorus</i>	4	32										
	<i>V. uliginosum</i>	4	0	Water: 0	Water: 0								
	<i>Carex rotundata</i>	4	0										
	<i>Betula nana</i>	0	28										
	<i>V. vitis-idaea</i>	0	4										
	<i>E. vaginatum</i>	0	4										
	<i>Ptilidium ciliare</i>	48	20										
	<i>Dicranum</i> sp.	8	20										
	Shrub	76	128										
	Herbaceous	4	4										
Intact 3	<i>E. vaginatum</i>	84	92	Litter: 0	Litter: 4	8.7 ± 0.8	8.3 ± 1.9	2.8	3.2	-	-	-	85
	<i>V. uliginosum</i>	24	20										
	<i>R. chamaemorus</i>	16	4										
	<i>E. nigrum</i>	12	20	Water: 12	Water: 0								
	<i>A. polifolia</i>	8	8										
	<i>B. nana</i>	8	12										
		32	0										

	<i>Sphagnum balticum</i>	0	8										
	<i>Dicranum</i> sp.	84	92										
	Herbaceous	68	64										
	Shrub												
Partly thawed 1	<i>C. rotundata</i>	52	0	Litter	Litter:	9.5 ±	7.0	3.3	3.2	-9.1 ±	-14.7	>85	>85
	<i>E. vaginatum</i>	0	80	: 0	0	0.6	±			4.6			
	<i>S. capillifolium</i>	100	100				1.2						
	Herbaceous	52	80	Water:	Water:								
	Shrub	0	0	r: 0	0								
Partly thawed 2	<i>C. rotundata</i>	52	60	Litter	Litter:	9.1 ±	10.9	3.2	3.8	-9.1 ±	-21	>85	>85
	<i>V. oxycoccos</i>	48	20	: 16	20	0.5	±			4.6			
	<i>A. polifolia</i>	28	24				1.0						
	<i>E. angustifolium</i>	0	8	Water:	Water:								
	<i>E. vaginatum</i>	0	4	r: 0	0								
	<i>Drosera rotundifolia</i>	0	4										
	<i>S. capillifolium</i>	100	72										
	<i>P. ciliare</i>	0	16										
	Herbaceous	52	76										
	Shrub	76	44										
Partly thawed 3	<i>V. oxycoccos</i>	16	36	Litter	Litter:	9.1 ±	10.9	3.3	3.4	-9.1 ±	-27	>85	>85
	<i>C. rotundata</i>	40	36	: 44	8	0.6	±			4.6			
	<i>E. angustifolium</i>	0	24				0.7						
	<i>S. capillifolium</i>	88	96	Water:	Water:								
	Herbaceous	40	60	r: 0	0								
	Shrub	40	36										
Fully thawed 1	<i>E. angustifolium</i>	96	100	Litter	Litter:	9.7 ±	8.7	5.1	5.7	2.1 ±	0	>85	>85
	<i>Equisetum fluviatile</i>	40	20	: 0	4	0.3	±			4.4			
	Herbaceous	136	120	Water:	Water:		0.4						
	Shrub	0	0	r: 12	0								
Fully thawed 2	<i>E. angustifolium</i>	88	100	Litter	Litter:	8.4 ±	9.6	5.0	6.0	2.1 ±	0	>85	>85
	<i>E. fluviatile</i>	24	68	: 0	0	1.0	±			4.4			
	<i>Comarum palustre</i>	4	12				0.3						
	<i>S. riparium</i>	12	0	Water:	Water:								
	Herbaceous	116	180	r: 0	0								
	Shrub	0	0										
Fully thawed 3	<i>E. angustifolium</i>	92	84	Litter	Litter:	9.1 ±	10.1	4.7	4.8	2.1 ±	0	>85	>85
	<i>S. riparium</i>	40	96	: 0	24	0.3	±			4.4			
	Herbaceous	92	84				0.4						
	Shrub	0	0	Water:	Water:								
				r: 0	0								

730

Table C2: Species included in the vegetation green area (GA) measurements per thaw stage. Mean GA (with standard deviation) is reported for each species across the three plots per thaw stage, and comprises the sum of stem and leaf green area (m² m⁻²).

Thaw stage	Species	Mean GA (m ² m ⁻²)
Intact	<i>Andromeda polifolia</i>	0.108 ± 0.06
	<i>Betula nana</i>	0.024 ± 0.02
	<i>Carex rotundata</i>	0.009 ± 0
	<i>Empetrum nigrum</i>	0.083 ± 0.07
	<i>Eriophorum vaginatum</i>	0.479 ± 0.54
	<i>Rubus chamaemorus</i>	0.160 ± 22.34
	<i>Vaccinium uliginosum</i>	0.190 ± 0.25
	<i>Vaccinium vitis-idaea</i>	0.005 ± 0.004
Partly thawed	<i>Andromeda polifolia</i>	0.035 ± 0.04
	<i>Betula nana</i>	0.016 ± 0.02
	<i>Carex rotundata</i>	0.163 ± 0.07
	<i>Drosera rotundifolia</i>	0.001 ± 0
	<i>Empetrum nigrum</i>	0.029 ± 0
	<i>Eriophorum angustifolium</i>	0.054 ± 0
	<i>Eriophorum vaginatum</i>	0.316 ± 0.16
	<i>Rubus chamaemorus</i>	0.026 ± 0
	<i>Vaccinium oxycoccos</i>	0.011 ± 0.01
	<i>Vaccinium uliginosum</i>	0.001 ± 0
Fully thawed	<i>Betula nana</i>	0.010 ± 0
	<i>Carex canescens</i>	0.003 ± 0
	<i>Comarum palustre</i>	0.086 ± 0.06
	<i>Equisetum fluviatile</i>	0.896 ± 0.63
	<i>Eriophorum angustifolium</i>	0.651 ± 0.64
	<i>Galium palustre</i>	0.012 ± 0

735

Table C3: Peat moisture data aggregated to daily medians from May-August periods in 2024 and 2025. Peat moisture was measured as volumetric water content (VWC, %) at each chamber. Date is expressed as YYYY-MM-DD.

date	chamber	thaw_stage	VWC
2024-05-14	1	intact	41.0605101
2024-05-15	1	intact	41.1284652
2024-05-16	1	intact	41.6925529
2024-05-17	1	intact	42.2016153
2024-05-18	1	intact	42.5223202
2024-05-19	1	intact	44.8038062
2024-05-20	1	intact	43.6937476
2024-05-21	1	intact	43.3301476
2024-05-22	1	intact	43.5006552
2024-05-23	1	intact	43.2403591
2024-05-24	1	intact	43.1114018
2024-05-25	1	intact	42.9779908
2024-05-26	1	intact	39.4578292
2024-05-27	1	intact	39.9465683
2024-05-28	1	intact	45.9747075
2024-05-29	1	intact	43.6734942
2024-05-30	1	intact	42.9068318
2024-05-31	1	intact	42.739248
2024-06-01	1	intact	42.9200879
2024-06-02	1	intact	42.697045
2024-06-03	1	intact	42.7556407
2024-06-04	1	intact	45.5608004
2024-06-05	1	intact	42.9458915
2024-06-06	1	intact	42.46882
2024-06-07	1	intact	42.2993965
2024-06-08	1	intact	42.3057493
2024-06-09	1	intact	42.229999
2024-06-10	1	intact	42.2858368
2024-06-11	1	intact	42.5450621
2024-06-12	1	intact	42.5045112
2024-06-13	1	intact	42.2792988
2024-06-14	1	intact	41.7452371
2024-06-15	1	intact	41.72232
2024-06-16	1	intact	41.6654059
2024-06-17	1	intact	41.7218161
2024-06-18	1	intact	42.1474714
2024-06-19	1	intact	42.1628706
2024-06-20	1	intact	41.5623153
2024-06-21	1	intact	42.1571109

2024-06-22	1	intact	41.7464336
2024-06-23	1	intact	41.3910747
2024-06-24	1	intact	42.0146809
2024-06-25	1	intact	42.2219108
2024-06-26	1	intact	41.7569689
2024-06-27	1	intact	41.5048579
2024-06-28	1	intact	41.4076303
2024-06-29	1	intact	41.558936
2024-06-30	1	intact	41.6865289
2024-07-01	1	intact	41.5572918
2024-07-02	1	intact	41.6468828
2024-07-03	1	intact	41.4396179
2024-07-04	1	intact	41.1977082
2024-07-05	1	intact	41.0962093
2024-07-06	1	intact	40.8885064
2024-07-07	1	intact	40.6928102
2024-07-08	1	intact	40.7722413
2024-07-09	1	intact	40.9942864
2024-07-10	1	intact	40.9023587
2024-07-11	1	intact	41.4654589
2024-07-12	1	intact	41.2064899
2024-07-13	1	intact	41.0474941
2024-07-14	1	intact	35.7947273
2024-07-15	1	intact	34.8900478
2024-07-16	1	intact	35.0700105
2024-07-17	1	intact	35.3165857
2024-07-18	1	intact	35.2525265
2024-07-19	1	intact	35.2496995
2024-07-20	1	intact	35.3519407
2024-07-21	1	intact	35.3741362
2024-07-22	1	intact	35.3358996
2024-07-23	1	intact	35.5018052
2024-07-24	1	intact	35.5543534
2024-07-25	1	intact	35.5738091
2024-07-26	1	intact	36.8698854
2024-07-27	1	intact	36.3863743
2024-07-28	1	intact	36.3465022
2024-07-29	1	intact	36.3155981
2024-07-30	1	intact	36.3269812
2024-07-31	1	intact	36.3614147

2024-08-01	1	intact	36.4497978
2024-08-02	1	intact	36.5660007
2024-08-03	1	intact	36.6090859
2024-08-04	1	intact	36.4899768
2024-08-05	1	intact	36.4324907
2024-08-06	1	intact	36.3707506
2024-08-07	1	intact	36.2436739
2024-08-08	1	intact	36.0350938
2024-08-09	1	intact	36.1075603
2024-08-10	1	intact	38.7570375
2024-08-11	1	intact	39.9771353
2024-08-12	1	intact	39.129402
2024-08-13	1	intact	38.0886619
2024-08-14	1	intact	37.7621626
2024-08-15	1	intact	37.7590662
2024-08-16	1	intact	37.7339249
2024-08-17	1	intact	38.1100251
2024-08-18	1	intact	37.7571963
2024-08-19	1	intact	38.5992006
2024-08-20	1	intact	38.0145145
2024-08-21	1	intact	37.72617
2024-08-22	1	intact	37.6849787
2024-08-23	1	intact	37.6408093
2024-08-24	1	intact	40.6025472
2024-08-25	1	intact	39.7633976
2024-08-26	1	intact	38.8518066
2024-08-27	1	intact	38.4906671
2024-08-28	1	intact	38.4274347
2024-08-29	1	intact	38.4430851
2024-08-30	1	intact	38.4820275
2024-08-31	1	intact	38.5266596
2025-05-19	1	intact	34.3399304
2025-05-20	1	intact	34.3668885
2025-05-21	1	intact	34.9092957
2025-05-22	1	intact	34.6029418
2025-05-23	1	intact	35.1063053
2025-05-24	1	intact	35.4680888
2025-05-25	1	intact	35.798061
2025-05-26	1	intact	36.4221714
2025-05-27	1	intact	36.7283591

2025-05-28	1	intact	36.484788
2025-05-29	1	intact	36.762761
2025-05-30	1	intact	36.5908181
2025-05-31	1	intact	36.4515043
2025-06-01	1	intact	36.3192213
2025-06-02	1	intact	36.878365
2025-06-03	1	intact	36.6368608
2025-06-04	1	intact	36.5252457
2025-06-05	1	intact	36.5697882
2025-06-06	1	intact	36.734546
2025-06-07	1	intact	36.9713132
2025-06-08	1	intact	39.0109161
2025-06-09	1	intact	37.7733121
2025-06-10	1	intact	37.8248662
2025-06-11	1	intact	37.4616858
2025-06-12	1	intact	37.3653948
2025-06-13	1	intact	37.350499
2025-06-14	1	intact	37.2339994
2025-06-15	1	intact	37.1396519
2025-06-16	1	intact	37.2104127
2025-06-17	1	intact	38.601145
2025-06-18	1	intact	37.9801786
2025-06-19	1	intact	37.517413
2025-06-20	1	intact	37.3551307
2025-06-21	1	intact	37.287688
2025-06-22	1	intact	37.3709688
2025-06-23	1	intact	37.4600688
2025-06-24	1	intact	37.5701231
2025-06-25	1	intact	37.7202259
2025-06-26	1	intact	37.7349142
2025-06-27	1	intact	37.5863211
2025-06-28	1	intact	37.667158
2025-06-29	1	intact	37.8840823
2025-06-30	1	intact	37.9937577
2025-07-01	1	intact	37.8382746
2025-07-02	1	intact	37.932973
2025-07-03	1	intact	37.8885515
2025-07-04	1	intact	37.8500175
2025-07-05	1	intact	37.8558833
2025-07-06	1	intact	37.9269764

2025-07-07	1	intact	38.0312946
2025-07-08	1	intact	38.1466912
2025-07-09	1	intact	38.1095332
2025-07-10	1	intact	38.0234441
2025-07-11	1	intact	38.1531378
2025-07-12	1	intact	38.3718072
2025-07-13	1	intact	38.5394924
2025-07-14	1	intact	38.6891127
2025-07-15	1	intact	38.819535
2025-07-16	1	intact	38.8414596
2025-07-17	1	intact	38.908572
2025-07-18	1	intact	38.998773
2025-07-19	1	intact	39.0516733
2025-07-20	1	intact	39.1832985
2025-07-21	1	intact	39.3484182
2025-07-22	1	intact	39.4353804
2025-07-23	1	intact	39.5367167
2025-07-24	1	intact	39.6149027
2025-07-25	1	intact	39.6217029
2025-07-26	1	intact	39.704586
2025-07-27	1	intact	39.7596666
2025-07-28	1	intact	40.6316854
2025-07-29	1	intact	42.0448957
2025-07-30	1	intact	42.8866136
2025-07-31	1	intact	42.5227909
2025-08-01	1	intact	43.0241339
2025-08-02	1	intact	42.956997
2025-08-03	1	intact	42.901445
2025-08-04	1	intact	42.7549333
2025-08-05	1	intact	43.6937008
2025-08-06	1	intact	43.4992494
2025-08-07	1	intact	43.4129464
2025-08-08	1	intact	43.2022341
2025-08-09	1	intact	43.2466535
2025-08-10	1	intact	43.3382094
2025-08-11	1	intact	43.8715466
2025-08-12	1	intact	43.7305426
2025-08-13	1	intact	43.9782491
2024-05-11	2	intact	58.2969594
2024-05-12	2	intact	64.1062899

2024-05-13	2	intact	72.0318297
2024-05-14	2	intact	80.170228
2024-05-15	2	intact	89.7283065
2024-05-16	2	intact	96.2713834
2024-07-22	2	intact	94.8884625
2024-07-23	2	intact	94.8096798
2024-07-24	2	intact	94.4829199
2024-07-25	2	intact	94.531827
2024-07-26	2	intact	95.126923
2024-07-27	2	intact	94.7515675
2024-07-28	2	intact	94.4436875
2024-07-29	2	intact	93.9859819
2024-07-30	2	intact	93.8746628
2024-07-31	2	intact	93.5588625
2024-08-01	2	intact	93.2904957
2024-08-02	2	intact	93.2791925
2024-08-03	2	intact	93.3097479
2024-08-04	2	intact	92.9387846
2024-08-05	2	intact	92.6046859
2024-08-06	2	intact	92.1410661
2024-08-07	2	intact	91.4638475
2024-08-08	2	intact	90.4810847
2024-08-09	2	intact	90.238477
2024-08-10	2	intact	90.293199
2024-08-11	2	intact	98.2432935
2024-08-12	2	intact	98.3081471
2024-08-13	2	intact	97.7041068
2024-08-14	2	intact	96.9494125
2024-08-15	2	intact	95.9790598
2024-08-16	2	intact	95.71334
2024-08-17	2	intact	97.0265295
2024-08-18	2	intact	96.5236913
2024-08-19	2	intact	96.1387949
2024-08-20	2	intact	96.6065714
2024-08-21	2	intact	95.7736692
2024-08-22	2	intact	95.2951666
2024-08-23	2	intact	94.935956
2024-08-24	2	intact	94.5526047
2025-05-14	2	intact	88.4097374
2025-05-15	2	intact	90.0687188

2025-05-16	2	intact	92.8086446
2025-05-17	2	intact	96.9311225
2025-05-18	2	intact	98.6169481
2024-05-10	3	intact	38.9609525
2024-05-11	3	intact	39.0881217
2024-05-12	3	intact	39.6648636
2024-05-13	3	intact	42.1605271
2024-05-14	3	intact	43.3112574
2024-05-15	3	intact	44.6099838
2024-05-16	3	intact	45.5385825
2024-05-17	3	intact	47.3084808
2024-05-18	3	intact	48.5035132
2024-05-19	3	intact	50.4007523
2024-05-20	3	intact	48.8658716
2024-05-21	3	intact	48.9658485
2024-05-22	3	intact	49.0844925
2024-05-23	3	intact	48.3587129
2024-05-24	3	intact	48.0686103
2024-05-25	3	intact	48.2605121
2024-05-26	3	intact	48.1289526
2024-05-27	3	intact	47.7895886
2024-05-28	3	intact	51.0075133
2024-05-29	3	intact	49.7429248
2024-05-30	3	intact	48.7647746
2024-05-31	3	intact	48.2659168
2024-06-01	3	intact	48.4430927
2024-06-02	3	intact	48.2907268
2024-06-03	3	intact	48.0020249
2024-06-04	3	intact	50.0020459
2024-06-05	3	intact	48.3963745
2024-06-06	3	intact	47.4932016
2024-06-07	3	intact	47.1561349
2024-06-08	3	intact	47.1254357
2024-06-09	3	intact	46.9239771
2024-06-10	3	intact	46.9932759
2024-06-11	3	intact	47.4347461
2024-06-12	3	intact	47.1513389
2024-06-13	3	intact	46.8688216
2024-06-14	3	intact	46.6469283
2024-06-15	3	intact	46.1604873

2024-06-16	3	intact	46.2152407
2024-06-17	3	intact	45.7201649
2024-06-18	3	intact	46.1929062
2024-06-19	3	intact	46.9220416
2024-06-20	3	intact	45.8938354
2024-06-21	3	intact	46.6408514
2024-06-22	3	intact	46.5725281
2024-06-23	3	intact	46.2489897
2024-06-24	3	intact	46.494786
2024-06-25	3	intact	46.7193126
2024-06-26	3	intact	46.3026069
2024-06-27	3	intact	46.3027376
2024-06-28	3	intact	46.0341589
2024-06-29	3	intact	45.8313789
2024-06-30	3	intact	45.7578394
2024-07-01	3	intact	45.5795378
2024-07-02	3	intact	45.7009313
2024-07-03	3	intact	45.6072897
2024-07-04	3	intact	45.1725268
2024-07-05	3	intact	45.0066554
2024-07-06	3	intact	44.882393
2024-07-07	3	intact	44.8080611
2024-07-08	3	intact	45.016208
2024-07-09	3	intact	45.1913102
2024-07-10	3	intact	45.1876413
2024-07-11	3	intact	45.1514322
2024-07-12	3	intact	44.8994898
2024-07-13	3	intact	45.0352276
2024-07-14	3	intact	45.0179801
2024-07-15	3	intact	44.8791047
2024-07-16	3	intact	44.3087749
2024-07-17	3	intact	44.5601726
2024-07-18	3	intact	44.3087749
2024-07-19	3	intact	44.2573307
2024-07-20	3	intact	44.3212085
2024-07-21	3	intact	43.854425
2024-07-22	3	intact	43.548669
2024-07-23	3	intact	43.4062449
2024-07-24	3	intact	43.6958188
2024-07-25	3	intact	43.7022027

2024-07-26	3	intact	44.1455961
2024-07-27	3	intact	43.7387816
2024-07-28	3	intact	43.6565068
2024-07-29	3	intact	43.4274296
2024-07-30	3	intact	43.1971473
2024-07-31	3	intact	43.3772167
2024-08-01	3	intact	43.4211504
2024-08-02	3	intact	43.6283881
2024-08-03	3	intact	43.5999975
2024-08-04	3	intact	43.5209945
2024-08-05	3	intact	43.5849323
2024-08-06	3	intact	43.4944053
2024-08-07	3	intact	43.2090827
2024-08-08	3	intact	42.878589
2024-08-09	3	intact	43.2093403
2024-08-10	3	intact	44.8511958
2024-08-11	3	intact	45.3509339
2024-08-12	3	intact	45.2068126
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2025-07-17	9	fully_thawed	100
2025-07-18	9	fully_thawed	100
2025-07-19	9	fully_thawed	100
2025-07-20	9	fully_thawed	100
2025-07-21	9	fully_thawed	100
2025-07-22	9	fully_thawed	100
2025-07-23	9	fully_thawed	100
2025-07-24	9	fully_thawed	100
2025-07-25	9	fully_thawed	100
2025-07-26	9	fully_thawed	100
2025-07-27	9	fully_thawed	100
2025-07-28	9	fully_thawed	100
2025-07-29	9	fully_thawed	100
2025-07-30	9	fully_thawed	100
2025-07-31	9	fully_thawed	100
2025-08-01	9	fully_thawed	100
2025-08-02	9	fully_thawed	100
2025-08-03	9	fully_thawed	100

740

2025-08-04	9	fully_thawed	100
2025-08-05	9	fully_thawed	100
2025-08-06	9	fully_thawed	100
2025-08-07	9	fully_thawed	100
2025-08-08	9	fully_thawed	100
2025-08-09	9	fully_thawed	100
2025-08-10	9	fully_thawed	100
2025-08-11	9	fully_thawed	100
2025-08-12	9	fully_thawed	100
2025-08-13	9	fully_thawed	100

745

750

755

Table C4: Vascular plant species growing directly on the peat cores and their leaf, stem, and flower biomass. As peat cores were selected to represent each individual chamber, the core and chamber plots have the same ID number. Note that the biomass estimates are likely underestimations due to some plant material being lost in the field. We show this table primarily for the species list.

Plot	Species	Biomass (g)			Total
		Leaf	Stem	Flower	
Intact 1	<i>E. vaginatum</i>	0.067	0.003	0	0.071
	<i>V. uliginosum</i>	0.136	0.554	0	0.690
	<i>E. nigrum</i>	0.021	0.023	0	0.044
	<i>A. polifolia</i>	0.071	0.048	0	0.119
	<i>R. chamaemorus</i>	0.032	0.008	0	0.040
Intact 3	<i>V. uliginosum</i>	0.016	0.091	0	0.107
	<i>E. nigrum</i>	0.098	0.152	0	0.250
	<i>A. polifolia</i>	0.248	0.333	0	0.582
	<i>E. vaginatum</i>	0.009	0	0	0.009
Intact 5	<i>E. vaginatum</i>	0.516	0.045	0	0.562
	<i>A. polifolia</i>	0.100	0.032	0	0.132
	<i>E. nigrum</i>	0.411	0.534	0	0.945
	<i>V. uliginosum</i>	0.096	0.362	0	0.457
	<i>V. oxycoccos</i>	0.018	0.031	0	0.050
Partly thawed 2	<i>E. vaginatum</i>	1.192	0.453	0.025	1.670
Partly thawed 4	<i>E. angustifolium</i>	0.005	0.112	0	0.117
	<i>V. oxycoccos</i>	0.006	0.009	0	0.016
	<i>A. polifolia</i>	0.047	0.031	0.008	0.086
	<i>C. rotundata</i>	0.068	0.078	0	0.146
Partly thawed 6	<i>V. oxycoccos</i>	0.045	0.047	0	0.092
	<i>C. rotundata</i>	0.509	0.100	0.033	0.643
	<i>E. angustifolium</i>	0.113	0.060	0	0.173
Fully thawed 7	<i>E. angustifolium</i>	0.005	0.004	0	0.009
Fully thawed 8	NA (only dead vegetation)	0	0	0	0
Fully thawed 9	<i>E. angustifolium</i>	0.010	0	0	0.010

760

Table C5: Automated chamber CH₄ flux (mg CH₄ m⁻² d⁻¹) and peat temperature data aggregated to daily scale with medians (CH₄ flux) and means (CH₄ flux and peat temperature). Each thaw stage (intact, partly thawed and fully thawed permafrost) has three

765

chambers, resulting in 9 chambers in total across the gradient. Date is reported as YYYY-MM-DD. Peat temperature was measured at each chamber in °C.

date	chamber_id	ch4_flux_mgch4m2d1 median	ch4_flux_mgch4m2d1 mean	peat_temp	thaw_stage
2023-05-19	1	-0.2219145	-0.3145721	5.1625	intact
2023-05-20	1	0.00574399	-0.066311	7.025	intact
2023-05-21	1	-0.3989296	-0.2403219	8.22857143	intact
2023-05-22	1	-0.7773529	-0.6796529	8.74285714	intact
2023-05-23	1	0.53550176	0.80188001	9.575	intact
2023-05-24	1	0.00458017	0.05634888	6.9875	intact
2023-05-25	1	-0.3354689	-0.2465779	6.175	intact
2023-05-26	1	-0.2424118	-0.2141699	4.64	intact
2023-05-27	1	-0.4223987	-0.5790264	4.53333333	intact
2023-05-28	1	0.31664522	0.13312589	7.91666667	intact
2023-05-29	1	-0.2720298	-0.3088527	6.74	intact
2023-05-30	1	-0.8175203	-0.8096751	6.0625	intact
2023-05-31	1	-0.2975853	-0.2703059	5.41428571	intact
2023-06-01	1	-0.2607799	-0.2098863	4.18571429	intact
2023-06-02	1	-0.0602156	-0.192396	5.975	intact
2023-06-03	1	-0.3074867	-0.1193395	6.6875	intact
2023-06-04	1	-0.2435461	-0.3969697	6.425	intact
2023-06-05	1	-0.1268613	-0.0325668	5.525	intact
2023-06-06	1	-0.2170739	-0.1498328	6.2	intact
2023-06-07	1	-0.1004278	-0.253325	7.05	intact
2023-06-08	1	0.00530328	0.02916815	6.775	intact
2023-06-09	1	0.37509357	0.13051516	8.775	intact
2023-06-10	1	-0.3912885	0.75210652	10.3875	intact
2023-06-11	1	-0.2676505	7.10531651	10.25	intact
2023-06-12	1	-0.1921932	0.00541212	9.91428571	intact
2023-06-13	1	-0.1997423	-0.0672235	9.14285714	intact
2023-06-14	1	-0.2465116	-0.1894103	9.2875	intact
2023-06-15	1	0.05328964	-0.0747067	8.9875	intact
2023-06-16	1	-0.7401661	-0.7508377	11.2375	intact
2023-06-17	1	-1.4492469	-1.9318429	13.275	intact
2023-06-18	1	-1.0694678	0.87740401	14.84	intact
2023-06-19	1	-1.800643	-1.4149338	15.4428571	intact
2023-06-20	1	-0.6641352	-0.8904488	15.325	intact
2023-06-21	1	0.64270481	1.29724865	14.95	intact
2023-06-22	1	-0.4805503	-1.0409474	15.15	intact

2023-06-23	1	-0.6481454	-0.2488546	14.6375	intact
2023-06-24	1	-0.5993958	-0.394253	12.3428571	intact
2023-06-25	1	-0.4903666	-0.2397805	11.6666667	intact
2023-06-26	1	-0.5284011	0.1425571	12.1666667	intact
2023-06-27	1	-0.6145895	-0.5465485	13.8285714	intact
2023-06-28	1	-0.4817611	-0.9907697	15.4428571	intact
2023-06-29	1	-0.5613113	0.09582892	16.5428571	intact
2023-06-30	1	-0.4806346	-0.557347	15.6	intact
2023-07-01	1	-0.2826519	-0.1860474	14.2875	intact
2023-07-02	1	-0.4020796	-0.457094	11.5666667	intact
2023-07-03	1	-0.1175917	-0.1317261	9.725	intact
2023-07-04	1	-0.9511043	5.18601466	11.7428571	intact
2023-07-05	1	-0.0827968	0.50823061	11.8375	intact
2023-07-06	1	-0.6713553	-0.4815579	11.8285714	intact
2023-07-07	1	-0.4162389	-0.4627183	13.7375	intact
2023-07-08	1	-0.6107624	-0.822446	14.62	intact
2023-07-09	1	-0.8287876	-0.2605612	14.0285714	intact
2023-07-10	1	-0.7495102	-0.5675542	14.42	intact
2023-07-11	1	-1.1428114	1.8352124	15.6571429	intact
2023-07-12	1	-0.264203	0.62863331	14.725	intact
2023-07-13	1	0.30660979	0.07871734	NA	intact
2023-07-14	1	-0.37722	0.35502003	12.6666667	intact
2023-07-15	1	-0.307862	-0.0255148	13.28	intact
2023-07-16	1	0.87609888	4.27861634	10.3	intact
2023-07-17	1	0.54447304	0.01754673	12.0571429	intact
2023-07-18	1	-0.0222388	-0.0045902	13.12	intact
2023-07-19	1	0.04262962	-0.1162991	11.8125	intact
2023-07-20	1	-0.3077424	0.01642977	11.4375	intact
2023-07-21	1	-0.730497	-0.7647286	11.6625	intact
2023-07-22	1	-0.4557989	-0.2553269	11.175	intact
2023-07-23	1	0.08321685	0.06964423	11.15	intact
2023-07-24	1	-1.0823346	-0.6294407	11.85	intact
2023-07-25	1	0.23061168	0.17592716	NA	intact
2023-07-26	1	0.43042129	0.43546101	NA	intact
2023-07-27	1	-1.1120897	-1.9148722	15.5333333	intact
2023-07-28	1	-1.4984701	-0.7081041	15.6833333	intact
2023-07-29	1	-0.7309139	-0.4819648	16.1625	intact
2023-07-30	1	-0.6813467	-0.5499898	14.375	intact
2023-07-31	1	-0.3995869	-0.0666944	13.9125	intact

2023-08-01	1	0.71797433	0.47320162	14.1	intact
2023-08-02	1	0.5240144	0.40927706	13.125	intact
2023-08-03	1	0.70216274	0.31239212	14.8	intact
2023-08-04	1	-1.0410518	-0.819665	14.5625	intact
2023-08-05	1	-1.1166625	-0.6333762	13.7285714	intact
2023-08-06	1	-0.1846842	2.34459431	12.525	intact
2023-08-07	1	0.64036517	0.62939795	NA	intact
2023-08-08	1	0.56232602	0.57082066	13.65	intact
2023-08-09	1	0.49790533	0.30370317	15.9	intact
2023-08-10	1	1.62976456	1.99928284	13.925	intact
2023-08-11	1	-0.8208423	-0.692715	12.6375	intact
2023-08-12	1	-0.3957228	-0.1429495	12.6875	intact
2023-08-13	1	0.58199905	16.0796192	12.4125	intact
2023-08-14	1	-1.6018361	-1.2600474	13.2	intact
2023-08-15	1	1.96973079	0.60415503	14.5875	intact
2023-08-16	1	1.08742737	2.03264989	12.4625	intact
2023-08-17	1	-1.0586454	-1.801549	12.8571429	intact
2023-08-18	1	0.31386682	10.3882639	12.175	intact
2023-08-19	1	-0.4316554	2.34089622	11.125	intact
2023-08-20	1	0.96403144	0.6801524	12.4166667	intact
2023-08-21	1	1.12343883	1.58686252	12.8375	intact
2023-08-22	1	1.77512416	1.94160349	13.1375	intact
2023-08-23	1	1.85619071	2.24923757	13.2125	intact
2023-08-24	1	-1.6412122	-1.7128361	11.8875	intact
2023-08-25	1	2.44681588	3.7409409	12.1625	intact
2023-08-26	1	0.73525343	5.42349674	NA	intact
2023-08-27	1	1.80610263	7.24959603	NA	intact
2023-08-28	1	1.11419173	1.63513396	NA	intact
2023-08-29	1	2.44297621	3.4181588	NA	intact
2023-08-30	1	1.74860916	0.68099281	NA	intact
2023-05-19	2	4.13109575	5.30438908	3.7125	partly_thawed
2023-05-20	2	2.94946211	4.52922979	4.7625	partly_thawed
2023-05-21	2	3.75940107	3.32820164	5.4125	partly_thawed
2023-05-22	2	9.71601188	11.8834351	5.0125	partly_thawed
2023-05-23	2	8.64402196	8.77209159	5.725	partly_thawed
2023-05-24	2	5.9103027	7.70046925	4.6125	partly_thawed
2023-05-25	2	2.53530721	2.4902531	4.2125	partly_thawed
2023-05-26	2	2.21262345	3.92609674	3.6	partly_thawed
2023-05-27	2	3.49860115	4.48461301	3.3625	partly_thawed

2023-05-28	2	3.54034229	4.37367796	4.8875	partly_thawed
2023-05-29	2	2.0143938	3.26080324	4.8875	partly_thawed
2023-05-30	2	7.31216476	5.90158756	4.6375	partly_thawed
2023-05-31	2	6.24483776	10.2935466	4.3375	partly_thawed
2023-06-01	2	4.58040045	6.47404017	3.275	partly_thawed
2023-06-02	2	4.46709781	4.55250207	4.9375	partly_thawed
2023-06-03	2	5.90188832	7.0224574	6.0625	partly_thawed
2023-06-04	2	4.2667141	4.77867334	5.95	partly_thawed
2023-06-05	2	2.83789229	3.29481924	5.15	partly_thawed
2023-06-06	2	4.48985966	5.34541724	5.9625	partly_thawed
2023-06-07	2	10.6005436	9.26890327	6.375	partly_thawed
2023-06-08	2	3.4067355	8.56300614	5.7625	partly_thawed
2023-06-09	2	4.81953768	8.36351233	6.4375	partly_thawed
2023-06-10	2	6.97247438	13.015929	6.6	partly_thawed
2023-06-11	2	6.99941603	10.856649	7.8625	partly_thawed
2023-06-12	2	7.07488065	10.7138892	8.8	partly_thawed
2023-06-13	2	2.36880788	2.25271135	7.9875	partly_thawed
2023-06-14	2	3.69534969	4.09571708	7.7625	partly_thawed
2023-06-15	2	6.35737438	6.05617647	7.8	partly_thawed
2023-06-16	2	8.90876126	10.3740364	8.0375	partly_thawed
2023-06-17	2	13.7418455	25.127661	9.1625	partly_thawed
2023-06-18	2	21.3168396	26.4984381	10.35	partly_thawed
2023-06-19	2	44.1913954	42.7243893	11.6875	partly_thawed
2023-06-20	2	13.9612921	26.1758197	12.325	partly_thawed
2023-06-21	2	17.002752	27.0303765	12.9	partly_thawed
2023-06-22	2	9.881781	10.3891263	11.725	partly_thawed
2023-06-23	2	39.3443563	48.7176035	12.1625	partly_thawed
2023-06-24	2	22.9288347	41.1810605	10.6875	partly_thawed
2023-06-25	2	24.5395551	35.5304197	10.375	partly_thawed
2023-06-26	2	10.3553112	28.0368117	10.2	partly_thawed
2023-06-27	2	12.6763355	32.2712979	11.4125	partly_thawed
2023-06-28	2	26.8731422	38.8797463	12.275	partly_thawed
2023-06-29	2	41.6668303	57.5739375	12.7625	partly_thawed
2023-06-30	2	13.6235424	14.4740752	13.0625	partly_thawed
2023-07-01	2	14.0065013	15.2112271	12.725	partly_thawed
2023-07-02	2	17.7208562	31.5264027	12.2	partly_thawed
2023-07-03	2	12.1039969	18.2924083	10.5125	partly_thawed
2023-07-04	2	39.171177	52.0188426	10.25	partly_thawed
2023-07-05	2	30.2419011	53.8628489	11.5375	partly_thawed

2023-07-06	2	33.2095587	45.1043935	10.6625	partly_thawed
2023-07-07	2	19.3064479	28.9733211	11.275	partly_thawed
2023-07-08	2	27.7635213	53.059753	13.6625	partly_thawed
2023-07-09	2	24.4208601	49.0627616	11.725	partly_thawed
2023-07-10	2	80.350965	97.3248559	11.9625	partly_thawed
2023-07-11	2	23.3612211	52.4062577	12.9875	partly_thawed
2023-07-12	2	16.3920649	21.8967751	12.7375	partly_thawed
2023-07-13	2	26.1858718	26.8513289	13.375	partly_thawed
2023-07-14	2	19.0424557	30.9206373	13.225	partly_thawed
2023-07-15	2	28.6238958	29.9492367	13.25	partly_thawed
2023-07-16	2	24.3665506	52.7666653	10.7125	partly_thawed
2023-07-17	2	66.2401312	72.7004558	10.775	partly_thawed
2023-07-18	2	31.1485143	54.755032	12.1125	partly_thawed
2023-07-19	2	66.1085117	67.4925083	11.3125	partly_thawed
2023-07-20	2	84.775434	96.8885633	10.65	partly_thawed
2023-07-21	2	33.5436586	33.1759336	11.5	partly_thawed
2023-07-22	2	21.1983762	25.5808727	11.0875	partly_thawed
2023-07-23	2	22.028071	23.2037045	10.6	partly_thawed
2023-07-24	2	29.6826587	34.0491644	10.625	partly_thawed
2023-07-25	2	23.7492942	27.8349918	10.875	partly_thawed
2023-07-26	2	54.3186128	67.8238034	11.475	partly_thawed
2023-07-27	2	94.2142469	111.266677	12.625	partly_thawed
2023-07-28	2	79.8050552	81.573831	12.425	partly_thawed
2023-07-29	2	51.771095	56.0331814	13.95	partly_thawed
2023-07-30	2	55.6789601	61.591004	13.15	partly_thawed
2023-07-31	2	24.9750167	31.9803513	12.9625	partly_thawed
2023-08-01	2	22.0074125	25.333477	13.3125	partly_thawed
2023-08-02	2	19.9212208	22.9247948	12.175	partly_thawed
2023-08-03	2	22.2636145	29.6652963	12.425	partly_thawed
2023-08-04	2	34.0101748	42.4866362	12.825	partly_thawed
2023-08-05	2	35.7551955	50.5231466	12.35	partly_thawed
2023-08-06	2	75.4574909	90.1113282	10.475	partly_thawed
2023-08-07	2	31.5647914	33.2681439	11.6	partly_thawed
2023-08-08	2	29.7783092	33.5760874	11.475	partly_thawed
2023-08-09	2	21.8526552	35.5465001	13.625	partly_thawed
2023-08-10	2	68.1945167	78.9451332	13.5	partly_thawed
2023-08-11	2	24.4209532	44.3804393	12.575	partly_thawed
2023-08-12	2	43.2268626	54.1392085	12.3125	partly_thawed
2023-08-13	2	22.308178	37.5541739	11.775	partly_thawed

2023-08-14	2	45.2274227	60.1220255	12.7375	partly_thawed
2023-08-15	2	160.398896	124.061429	13.175	partly_thawed
2023-08-16	2	70.8737833	98.6087051	12.2125	partly_thawed
2023-08-17	2	46.837311	68.0622133	12.0875	partly_thawed
2023-08-18	2	54.9761659	77.4073484	10.9125	partly_thawed
2023-08-19	2	47.9671115	80.9321384	10.525	partly_thawed
2023-08-20	2	38.8002323	38.7045713	10.8625	partly_thawed
2023-08-21	2	42.9428792	64.183448	12.35	partly_thawed
2023-08-22	2	143.703647	135.560575	13.075	partly_thawed
2023-08-23	2	117.829983	107.771402	13.1857143	partly_thawed
2023-08-24	2	41.2154506	68.7661472	11.8875	partly_thawed
2023-08-25	2	68.6044776	72.5486917	11.4375	partly_thawed
2023-08-26	2	73.9180198	91.8405196	10.8375	partly_thawed
2023-08-27	2	50.7697585	44.059604	10.1125	partly_thawed
2023-08-28	2	30.4250286	37.2632671	10.725	partly_thawed
2023-08-29	2	47.3675987	53.5110577	12.1125	partly_thawed
2023-08-30	2	65.9836321	69.6352057	11.925	partly_thawed
2023-05-19	3	0.28242124	0.15261538	5.3875	intact
2023-05-20	3	0.65929647	0.83188033	7.175	intact
2023-05-21	3	0.40696228	0.03747182	8.625	intact
2023-05-22	3	-0.6184055	-0.51299	9.2875	intact
2023-05-23	3	0.24514895	-0.2272565	9.575	intact
2023-05-24	3	0.30435326	0.20411986	7.01428571	intact
2023-05-25	3	0.41032638	0.29485431	5.8	intact
2023-05-26	3	-0.6504395	-0.2873725	5.2	intact
2023-05-27	3	0.47876537	0.3438634	4.44	intact
2023-05-28	3	-0.3415914	-0.2238291	NA	intact
2023-05-29	3	-0.0529419	-0.1776445	6.83333333	intact
2023-05-30	3	0.22888423	0.10568133	6.12857143	intact
2023-05-31	3	0.32599017	-0.1156845	5.475	intact
2023-06-01	3	0.42555661	0.45697042	4.18333333	intact
2023-06-02	3	-0.2906701	0.09556482	6.05	intact
2023-06-03	3	0.29584067	0.2031516	6.775	intact
2023-06-04	3	0.2402857	0.17555923	6.4875	intact
2023-06-05	3	-0.0897059	-0.07366	5.4875	intact
2023-06-06	3	-0.0252225	0.08601608	6.325	intact
2023-06-07	3	0.58032685	0.19854514	7.2	intact
2023-06-08	3	-0.4394576	-0.4315094	6.85	intact
2023-06-09	3	-0.4314349	-1.3165384	8.9375	intact

2023-06-10	3	0.28334897	0.25267383	10.6142857	intact
2023-06-11	3	-0.2612394	0.89510087	10.25	intact
2023-06-12	3	-0.2946219	-0.5165592	10.0625	intact
2023-06-13	3	-0.0338286	0.3891821	9.1	intact
2023-06-14	3	-0.0907013	-0.1227327	9.3625	intact
2023-06-15	3	0.37245276	0.25697527	9.125	intact
2023-06-16	3	-0.4416667	-0.0272152	11.5	intact
2023-06-17	3	1.0803243	1.31124666	13.35	intact
2023-06-18	3	-0.805758	-1.7893154	15.0625	intact
2023-06-19	3	-0.318924	2.29680327	16.2428571	intact
2023-06-20	3	-0.0642428	1.35758451	15.44	intact
2023-06-21	3	0.7116629	-0.7651908	14.7	intact
2023-06-22	3	-0.133218	-0.0303343	15.2428571	intact
2023-06-23	3	0.89448854	0.70853471	14.7625	intact
2023-06-24	3	0.20661447	0.51858571	12.4333333	intact
2023-06-25	3	0.86352316	0.93431991	10.625	intact
2023-06-26	3	0.24864793	3.13974426	12.6285714	intact
2023-06-27	3	-0.0273573	2.16870067	14.1875	intact
2023-06-28	3	-0.5971706	-1.1064645	15.5125	intact
2023-06-29	3	0.92154582	1.98801112	16.025	intact
2023-06-30	3	0.20754081	0.30538573	15.2375	intact
2023-07-01	3	-0.2894433	-0.1906541	13.9333333	intact
2023-07-02	3	-0.0856144	0.12439697	11.2142857	intact
2023-07-03	3	0.39763121	0.41624183	9.625	intact
2023-07-04	3	0.54802072	10.4729404	12.2571429	intact
2023-07-05	3	-0.0315873	0.59065889	12.2125	intact
2023-07-06	3	0.01004317	-0.1895179	11.9857143	intact
2023-07-07	3	0.10155017	0.06742985	13.45	intact
2023-07-08	3	0.85755443	3.12882287	13.82	intact
2023-07-09	3	0.71818096	0.15651004	14.3	intact
2023-07-10	3	0.90556241	1.57753602	14.68	intact
2023-07-11	3	-0.0662303	3.77381243	15.95	intact
2023-07-12	3	-0.2491408	-0.2563105	14.65	intact
2023-07-13	3	-0.2446549	0.13056121	NA	intact
2023-07-14	3	0.24190531	0.3360966	13.175	intact
2023-07-15	3	-1.1251532	-0.6548019	13.28	intact
2023-07-16	3	0.38496131	5.74970142	10.5	intact
2023-07-17	3	-1.3307463	-1.4488457	12.9	intact
2023-07-18	3	-1.2616284	-0.5680806	12.95	intact

2023-07-19	3	0.77554292	0.76899666	11.85	intact
2023-07-20	3	1.35716245	2.99278933	11.2	intact
2023-07-21	3	-0.1583867	-0.0596001	11.325	intact
2023-07-22	3	0.34193804	0.12411425	11.2125	intact
2023-07-23	3	-0.2813089	-0.109558	11.1375	intact
2023-07-24	3	-0.3406919	0.24243278	12	intact
2023-07-25	3	0.25825101	0.49072928	NA	intact
2023-07-26	3	0.40345057	0.30363802	NA	intact
2023-07-27	3	-0.8741544	-0.2730387	15.7166667	intact
2023-07-28	3	2.32344831	1.97912623	15.4166667	intact
2023-07-29	3	1.03431846	0.05019303	15.975	intact
2023-07-30	3	2.28104972	3.3827716	14.15	intact
2023-07-31	3	0.51588929	0.27541063	13.9375	intact
2023-08-01	3	-0.6653183	-0.3017723	13.95	intact
2023-08-02	3	-0.1580113	-0.1861269	13.1375	intact
2023-08-03	3	-0.0312118	0.02398612	14.4375	intact
2023-08-04	3	-0.2318877	-0.3030711	14.825	intact
2023-08-05	3	1.74803945	1.47327998	13.675	intact
2023-08-06	3	3.25164539	5.2593024	12.2428571	intact
2023-08-07	3	-0.6453033	-0.9568866	NA	intact
2023-08-08	3	0.62686935	0.5055592	13.9428571	intact
2023-08-09	3	0.08627569	0.61711875	15.725	intact
2023-08-10	3	0.7454318	3.49928063	13.95	intact
2023-08-11	3	0.68158952	1.02352138	12.7	intact
2023-08-12	3	0.68443802	0.44428649	12.625	intact
2023-08-13	3	0.45153209	6.64623444	12.2	intact
2023-08-14	3	1.26148737	1.70842731	13.3	intact
2023-08-15	3	0.99743126	0.06598729	14.725	intact
2023-08-16	3	-0.2332361	0.84381694	12.5125	intact
2023-08-17	3	1.23112062	0.28531737	12.9	intact
2023-08-18	3	0.96186809	1.33282201	12.3	intact
2023-08-19	3	-0.6037053	2.5732883	11.175	intact
2023-08-20	3	0.4383174	0.39770614	12.5	intact
2023-08-21	3	-0.94329	-1.1745188	12.9375	intact
2023-08-22	3	-0.4447405	-0.4507022	13.15	intact
2023-08-23	3	0.003773	1.36948258	13.2875	intact
2023-08-24	3	-0.4029749	3.39401655	12.225	intact
2023-08-25	3	0.76561396	3.55360633	12.0285714	intact
2023-08-26	3	0.93901561	5.01737693	NA	intact

2023-08-27	3	1.12922045	9.14806285	NA	intact
2023-08-28	3	0.13618351	-0.0469931	NA	intact
2023-08-29	3	0.56588107	3.24386514	NA	intact
2023-08-30	3	-1.1958467	2.78704824	NA	intact
2023-05-19	4	15.3260797	15.3948808	5.65	partly_thawed
2023-05-20	4	15.8434423	15.3772993	5.65	partly_thawed
2023-05-21	4	14.2417932	15.0097768	7.9875	partly_thawed
2023-05-22	4	18.8625876	19.3399555	6.2	partly_thawed
2023-05-23	4	18.642289	17.545261	NA	partly_thawed
2023-05-24	4	21.6231619	17.9463034	NA	partly_thawed
2023-05-25	4	15.3458588	12.6499204	6.325	partly_thawed
2023-05-26	4	7.54260395	8.93673834	4.725	partly_thawed
2023-05-27	4	18.7376978	18.2696356	5.3125	partly_thawed
2023-05-28	4	15.3629006	13.7585135	7.1	partly_thawed
2023-05-29	4	8.01335246	8.20426006	6.7625	partly_thawed
2023-05-30	4	17.2074342	16.7919558	5.9875	partly_thawed
2023-05-31	4	13.6269659	12.4738069	5.4875	partly_thawed
2023-06-01	4	9.6420955	8.78661397	4.35	partly_thawed
2023-06-02	4	16.0230118	16.2797671	7.425	partly_thawed
2023-06-03	4	11.0791401	13.4145906	7.4625	partly_thawed
2023-06-04	4	10.1808821	11.2558409	7.9625	partly_thawed
2023-06-05	4	5.02753368	5.41797059	6.1875	partly_thawed
2023-06-06	4	7.80287108	8.82239757	8.15	partly_thawed
2023-06-07	4	22.8335209	20.9850252	8.8625	partly_thawed
2023-06-08	4	12.5212654	15.7086314	7.6625	partly_thawed
2023-06-09	4	10.1538324	12.6166097	10.0875	partly_thawed
2023-06-10	4	16.8196508	17.9681851	10.6875	partly_thawed
2023-06-11	4	17.1703155	18.5361708	10.0375	partly_thawed
2023-06-12	4	16.6059234	16.2817881	10.1	partly_thawed
2023-06-13	4	4.07412658	4.78916875	9.8625	partly_thawed
2023-06-14	4	9.18142196	10.5433621	10.425	partly_thawed
2023-06-15	4	9.95609545	10.8573951	9.85	partly_thawed
2023-06-16	4	19.1560774	18.5344379	13.25	partly_thawed
2023-06-17	4	23.2823381	23.0617603	14.15	partly_thawed
2023-06-18	4	27.1226898	25.7422247	15.6125	partly_thawed
2023-06-19	4	23.6041287	24.2344856	17.225	partly_thawed
2023-06-20	4	21.2917605	21.6602278	14.2	partly_thawed
2023-06-21	4	30.6550238	27.4131775	15.75	partly_thawed
2023-06-22	4	14.1761334	15.6023126	14.6875	partly_thawed

2023-06-23	4	29.6107856	32.0612092	15.475	partly_thawed
2023-06-24	4	26.1851638	25.3115567	13.15	partly_thawed
2023-06-25	4	19.1723247	22.8530436	13.5625	partly_thawed
2023-06-26	4	17.5173585	18.749753	13.1625	partly_thawed
2023-06-27	4	23.2891672	25.0480041	14.8875	partly_thawed
2023-06-28	4	27.026658	27.6241091	14.775	partly_thawed
2023-06-29	4	34.9020762	38.1669749	17.125	partly_thawed
2023-06-30	4	13.4209663	20.4740529	14.3875	partly_thawed
2023-07-01	4	22.8990118	21.8218528	13.125	partly_thawed
2023-07-02	4	30.5293099	28.459866	11.325	partly_thawed
2023-07-03	4	21.5750824	22.1733522	10.2875	partly_thawed
2023-07-04	4	38.6929169	39.0442357	13.075	partly_thawed
2023-07-05	4	28.1062865	30.1459577	11.9125	partly_thawed
2023-07-06	4	35.5901705	34.3911688	14.3875	partly_thawed
2023-07-07	4	26.4246888	28.7979284	13.85	partly_thawed
2023-07-08	4	20.2482046	24.1058125	15.25	partly_thawed
2023-07-09	4	35.9015093	34.5588775	15.625	partly_thawed
2023-07-10	4	41.3976089	40.7314678	16.075	partly_thawed
2023-07-11	4	41.5938532	42.5259194	15.5	partly_thawed
2023-07-12	4	26.1006239	28.7431757	13.3375	partly_thawed
2023-07-13	4	31.041448	30.0550752	13.9375	partly_thawed
2023-07-14	4	40.3052808	43.162112	13.575	partly_thawed
2023-07-15	4	32.1065483	30.2942149	14.2625	partly_thawed
2023-07-16	4	28.8956505	32.3777766	11.325	partly_thawed
2023-07-17	4	48.3482861	46.6741334	13.7375	partly_thawed
2023-07-18	4	41.0063463	38.6072954	14.0625	partly_thawed
2023-07-19	4	43.5113186	45.2993445	12.375	partly_thawed
2023-07-20	4	58.1198302	49.9005766	12.875	partly_thawed
2023-07-21	4	44.4942575	42.4367119	12.525	partly_thawed
2023-07-22	4	37.1977352	37.2852589	12.2375	partly_thawed
2023-07-23	4	36.2617427	31.6168443	12.125	partly_thawed
2023-07-24	4	36.6393035	34.4014538	13.125	partly_thawed
2023-07-25	4	35.4331152	34.6989108	13.5	partly_thawed
2023-07-26	4	41.8456117	38.6393134	15.0125	partly_thawed
2023-07-27	4	49.2020487	47.3216293	16.6	partly_thawed
2023-07-28	4	55.169586	55.248497	16.5	partly_thawed
2023-07-29	4	46.2299463	43.1308362	15.95	partly_thawed
2023-07-30	4	51.4052057	48.68909	14.3375	partly_thawed
2023-07-31	4	38.8404046	35.8706909	14.0125	partly_thawed

2023-08-01	4	43.0606422	43.8458035	14.7	partly_thawed
2023-08-02	4	44.7060991	42.6706483	13.95	partly_thawed
2023-08-03	4	34.382709	38.5229968	14.9625	partly_thawed
2023-08-04	4	43.6758417	42.6097425	15.5375	partly_thawed
2023-08-05	4	28.8372025	34.7937105	13.825	partly_thawed
2023-08-06	4	59.0955896	62.788	13.8625	partly_thawed
2023-08-07	4	48.3871803	48.7196695	12.7	partly_thawed
2023-08-08	4	51.7724684	50.7905241	15.225	partly_thawed
2023-08-09	4	38.4434676	42.0341417	15.875	partly_thawed
2023-08-10	4	74.9909469	77.0483852	14.6875	partly_thawed
2023-08-11	4	55.5844904	60.3671212	13.8125	partly_thawed
2023-08-12	4	66.6026489	67.2746802	14.175	partly_thawed
2023-08-13	4	58.589253	64.0130665	12.8125	partly_thawed
2023-08-14	4	83.0673361	79.7021874	14.5625	partly_thawed
2023-08-15	4	89.1140624	89.2577606	15.975	partly_thawed
2023-08-16	4	87.0601228	90.9022928	13.4375	partly_thawed
2023-08-17	4	67.5630045	62.9590444	14.0625	partly_thawed
2023-08-18	4	74.5207843	70.3560364	12.675	partly_thawed
2023-08-19	4	72.6660605	76.2211604	12.525	partly_thawed
2023-08-20	4	47.6804448	52.417741	13	partly_thawed
2023-08-21	4	69.7409064	74.3706168	14.3125	partly_thawed
2023-08-22	4	103.851364	108.870645	15.0375	partly_thawed
2023-08-23	4	100.810651	103.065426	15.3375	partly_thawed
2023-08-24	4	98.2969009	93.9909804	13.5375	partly_thawed
2023-08-25	4	77.4292843	78.8877952	12.65	partly_thawed
2023-08-26	4	71.6129038	75.9783125	13.525	partly_thawed
2023-08-27	4	87.5944317	80.6300486	11.925	partly_thawed
2023-08-28	4	59.782811	60.123705	12.1625	partly_thawed
2023-08-29	4	96.4069224	103.531189	13.1375	partly_thawed
2023-08-30	4	109.6439	108.307258	14.275	partly_thawed
2023-05-19	5	-0.0251655	-0.2040148	5.55	intact
2023-05-20	5	-0.2815876	-0.1156674	6.8375	intact
2023-05-21	5	-0.0128425	-0.2529357	7.725	intact
2023-05-22	5	1.13846109	4.86783665	7.6875	intact
2023-05-23	5	0.03762361	5.35088145	7.075	intact
2023-05-24	5	0.68078451	0.52926372	5.9875	intact
2023-05-25	5	-0.0359756	-0.203844	4.55	intact
2023-05-26	5	0.04524934	0.04812912	3.65	intact
2023-05-27	5	-0.3080117	-0.0685212	4.65	intact

2023-05-28	5	0.05947033	0.15642894	6.675	intact
2023-05-29	5	-0.4193692	-0.2105441	5.3625	intact
2023-05-30	5	0.42612454	0.37590872	5.3	intact
2023-05-31	5	0.09737126	0.1007778	4.375	intact
2023-06-01	5	0.41931014	0.67524052	3.4375	intact
2023-06-02	5	0.51340476	-0.1051708	5.675	intact
2023-06-03	5	-0.3604455	-0.3624306	5.7875	intact
2023-06-04	5	-0.3352774	-0.3292613	5.8625	intact
2023-06-05	5	0.29650586	0.08976407	4.6	intact
2023-06-06	5	0.29522394	0.04881347	5.5125	intact
2023-06-07	5	0.41065004	0.14334422	6.5375	intact
2023-06-08	5	-0.2631071	0.09009892	5.3125	intact
2023-06-09	5	0.07342837	5.00581528	7.1875	intact
2023-06-10	5	0.05336857	4.94258043	7.775	intact
2023-06-11	5	0.72256387	3.05219001	9.2625	intact
2023-06-12	5	0.42412964	1.00882438	8.925	intact
2023-06-13	5	-0.3177511	-0.2192402	7.9375	intact
2023-06-14	5	-0.0623086	-0.0201624	8.325	intact
2023-06-15	5	0.12853273	0.01134575	8.2375	intact
2023-06-16	5	-0.5996864	-0.6132317	10.65	intact
2023-06-17	5	-0.3939054	-1.2309494	11.275	intact
2023-06-18	5	1.03784111	3.26013278	12.9625	intact
2023-06-19	5	0.64445063	4.70022052	14.1	intact
2023-06-20	5	-1.9160745	-1.3170517	15.825	intact
2023-06-21	5	1.43174456	4.94086096	14.675	intact
2023-06-22	5	14.5897185	27.5451175	15.95	intact
2023-06-23	5	14.5860744	25.1118206	14.4	intact
2023-06-24	5	3.67560803	2.52014476	11.1125	intact
2023-06-25	5	2.55655259	1.31037591	11.5875	intact
2023-06-26	5	9.05582828	14.1506646	13.95	intact
2023-06-27	5	19.4938737	18.5075612	15.7625	intact
2023-06-28	5	3.68693252	3.87986092	14.7	intact
2023-06-29	5	42.87176	55.3274336	14.8375	intact
2023-06-30	5	31.8379188	31.175372	15.7875	intact
2023-07-01	5	77.3669118	92.6742226	14.875	intact
2023-07-02	5	86.4779433	76.6820233	11.5875	intact
2023-07-03	5	42.2123819	53.1488351	11.7875	intact
2023-07-04	5	40.1150495	42.8141171	12.375	intact
2023-07-05	5	2.89235452	9.47502849	11.025	intact

2023-07-06	5	6.52251839	17.6682207	12.2375	intact
2023-07-07	5	19.3111916	19.58588	13.8875	intact
2023-07-08	5	7.72584268	14.8962392	13.925	intact
2023-07-09	5	4.05604454	2.17828788	13.525	intact
2023-07-10	5	23.7444273	36.3046591	13.7	intact
2023-07-11	5	39.538247	42.797092	15.8125	intact
2023-07-12	5	3.63369206	12.227283	14.0125	intact
2023-07-13	5	36.1857136	35.4577445	14.3125	intact
2023-07-14	5	17.8959163	22.0494318	14.6375	intact
2023-07-15	5	2.93729053	3.51853312	13.2	intact
2023-07-16	5	25.4409511	23.9423046	11.25	intact
2023-07-17	5	30.0283404	29.7213781	13.525	intact
2023-07-18	5	3.48866727	5.74666902	12.6625	intact
2023-07-19	5	8.49712006	7.90516831	11.725	intact
2023-07-20	5	79.9097731	80.9678286	12.4875	intact
2023-07-21	5	46.0929503	47.3835864	12.8	intact
2023-07-22	5	15.822715	22.6153466	12.125	intact
2023-07-23	5	25.9418801	26.9434791	12.4875	intact
2023-07-24	5	41.6494707	35.438396	13.7	intact
2023-07-25	5	51.2553575	52.2977835	14.625	intact
2023-07-26	5	50.7803873	60.1438815	15.0875	intact
2023-07-27	5	38.5916977	44.0686328	14.3375	intact
2023-07-28	5	40.664371	53.2797467	14.6125	intact
2023-07-29	5	10.9023469	12.1773874	14.3375	intact
2023-07-30	5	35.5344519	37.1523359	14.575	intact
2023-07-31	5	27.8033055	32.645376	14.5875	intact
2023-08-01	5	39.8192712	46.5040767	14.5875	intact
2023-08-02	5	33.1918338	40.9258595	14.4875	intact
2023-08-03	5	26.6571166	20.6653901	15.1625	intact
2023-08-04	5	32.2463183	44.9244439	14.9125	intact
2023-08-05	5	13.9493778	23.896496	12.6625	intact
2023-08-06	5	75.8253915	79.1372214	12.0625	intact
2023-08-07	5	62.0275455	64.2055756	12.675	intact
2023-08-08	5	46.1963654	54.0385145	15.5125	intact
2023-08-09	5	26.5256764	44.7651636	15.475	intact
2023-08-10	5	92.8947529	87.2108676	13.6875	intact
2023-08-11	5	85.7433681	78.3819607	13.0875	intact
2023-08-12	5	32.8176831	46.5376787	13.9	intact
2023-08-13	5	71.2841821	66.5311746	12.875	intact

2023-08-14	5	76.0603196	77.0281032	14.025	intact
2023-08-15	5	61.2518558	74.7160673	13.9125	intact
2023-08-16	5	74.938378	71.5146573	12.6	intact
2023-08-17	5	10.3617386	11.3624915	12.0625	intact
2023-08-18	5	20.8561353	25.9445849	10.9375	intact
2023-08-19	5	48.1623514	71.1001884	11.6	intact
2023-08-20	5	47.4928991	56.7325931	12.6125	intact
2023-08-21	5	59.9468901	48.8358025	13.4	intact
2023-08-22	5	56.257235	57.3824881	13.4875	intact
2023-08-23	5	54.5211725	58.7325399	13.35	intact
2023-08-24	5	73.8134836	77.1484314	12.75	intact
2023-08-25	5	78.2430376	89.5674388	12	intact
2023-08-26	5	70.5265326	66.6240402	12.0625	intact
2023-08-27	5	58.3734518	58.862783	11.2625	intact
2023-08-28	5	29.1387184	45.334858	11.775	intact
2023-08-29	5	43.3536866	50.8089725	12.45	intact
2023-08-30	5	96.3562445	93.1586661	12.55	intact
2023-05-19	6	8.22055435	8.36940269	2.7875	partly_thawed
2023-05-20	6	10.0807689	10.5066268	3.0875	partly_thawed
2023-05-21	6	18.0408983	20.3644724	4.025	partly_thawed
2023-05-22	6	20.0728355	19.6821984	3.8	partly_thawed
2023-05-23	6	19.8541094	18.4981734	4.4125	partly_thawed
2023-05-24	6	13.2493831	16.0246948	3.75	partly_thawed
2023-05-25	6	15.7558773	15.7560188	3.0125	partly_thawed
2023-05-26	6	14.6898552	16.3776553	3.0875	partly_thawed
2023-05-27	6	12.4038263	17.9471328	3.2625	partly_thawed
2023-05-28	6	14.3445595	15.3652945	4.4375	partly_thawed
2023-05-29	6	17.7840109	16.6526554	4.2375	partly_thawed
2023-05-30	6	20.0638626	20.1224406	3.975	partly_thawed
2023-05-31	6	21.5137204	22.4310255	3.9375	partly_thawed
2023-06-01	6	16.1449866	16.8554831	3.25	partly_thawed
2023-06-02	6	21.4132642	22.4076818	4.7875	partly_thawed
2023-06-03	6	23.4707426	23.0540833	5.6375	partly_thawed
2023-06-04	6	17.0908635	18.5687625	5.3	partly_thawed
2023-06-05	6	11.2882837	10.2126407	4.8625	partly_thawed
2023-06-06	6	16.9432259	16.8660376	5.55	partly_thawed
2023-06-07	6	23.442394	24.3577983	6.2	partly_thawed
2023-06-08	6	19.689198	21.7679062	5.75	partly_thawed
2023-06-09	6	30.7806593	30.0382616	6.5875	partly_thawed

2023-06-10	6	29.6977711	30.092162	6.3875	partly_thawed
2023-06-11	6	19.6793493	24.2542025	7.2625	partly_thawed
2023-06-12	6	16.157194	21.4507637	7.85	partly_thawed
2023-06-13	6	10.1582938	9.79526147	7.2625	partly_thawed
2023-06-14	6	20.2614767	20.6581517	7.5625	partly_thawed
2023-06-15	6	21.7092025	22.3232356	7.3375	partly_thawed
2023-06-16	6	38.2572792	35.2009128	8.175	partly_thawed
2023-06-17	6	39.1763921	34.2166381	8.7625	partly_thawed
2023-06-18	6	37.9001712	36.2820037	9.6	partly_thawed
2023-06-19	6	40.0347046	40.0491413	10.775	partly_thawed
2023-06-20	6	25.1664938	31.2181789	11.0625	partly_thawed
2023-06-21	6	39.1694686	42.1963156	11.9125	partly_thawed
2023-06-22	6	12.3492412	17.1607488	11.2375	partly_thawed
2023-06-23	6	43.5449617	47.1659297	13.275	partly_thawed
2023-06-24	6	40.9599485	39.947581	11.475	partly_thawed
2023-06-25	6	33.7630086	37.5147382	10.9875	partly_thawed
2023-06-26	6	13.5229454	24.8245029	10.1125	partly_thawed
2023-06-27	6	20.7579681	31.147547	11.325	partly_thawed
2023-06-28	6	34.0001316	38.2315613	11.9375	partly_thawed
2023-06-29	6	57.9189061	57.6365163	12.025	partly_thawed
2023-06-30	6	17.541349	26.1626504	12.1625	partly_thawed
2023-07-01	6	19.7927166	20.6067129	12.1875	partly_thawed
2023-07-02	6	32.9973847	38.1155083	10.9125	partly_thawed
2023-07-03	6	12.0365407	18.1963014	9.7625	partly_thawed
2023-07-04	6	77.5904311	67.8668564	9.3875	partly_thawed
2023-07-05	6	42.6626879	47.3393034	10.55	partly_thawed
2023-07-06	6	43.1515249	45.3354218	10.5375	partly_thawed
2023-07-07	6	20.2174368	38.4991831	10.7125	partly_thawed
2023-07-08	6	39.6743724	48.4818878	12.625	partly_thawed
2023-07-09	6	48.1502657	45.6027901	11.45	partly_thawed
2023-07-10	6	85.2151002	80.9096284	11.1875	partly_thawed
2023-07-11	6	62.5039758	65.9324879	12.2125	partly_thawed
2023-07-12	6	22.9181234	25.330108	12	partly_thawed
2023-07-13	6	23.9994698	34.1472324	11.8	partly_thawed
2023-07-14	6	19.2792223	37.3581303	11.7625	partly_thawed
2023-07-15	6	48.9913041	48.3724217	12.5125	partly_thawed
2023-07-16	6	20.0868713	33.8979963	10.25	partly_thawed
2023-07-17	6	64.236184	53.7913356	10.8	partly_thawed
2023-07-18	6	50.322429	52.7552287	12.025	partly_thawed

2023-07-19	6	49.8566426	55.3955589	10.925	partly_thawed
2023-07-20	6	58.7793876	69.4519487	10.5125	partly_thawed
2023-07-21	6	31.8481451	40.8008804	10.8875	partly_thawed
2023-07-22	6	26.4707146	26.8150754	10.8625	partly_thawed
2023-07-23	6	29.127419	31.8537345	10.6125	partly_thawed
2023-07-24	6	31.3779504	29.9220072	10.6375	partly_thawed
2023-07-25	6	32.8231256	34.8159151	11.475	partly_thawed
2023-07-26	6	50.4473485	54.8340509	11.9	partly_thawed
2023-07-27	6	110.332247	97.0265119	12.275	partly_thawed
2023-07-28	6	92.7295683	89.1958493	12.6375	partly_thawed
2023-07-29	6	60.3420529	59.6087259	13.575	partly_thawed
2023-07-30	6	53.361103	56.3148631	12.6375	partly_thawed
2023-07-31	6	29.3270414	28.8761465	12.2875	partly_thawed
2023-08-01	6	36.8111944	41.5758528	12.3	partly_thawed
2023-08-02	6	48.9128661	47.4309069	12.9375	partly_thawed
2023-08-03	6	27.0428055	28.6326007	13.25	partly_thawed
2023-08-04	6	48.4321356	48.9716458	13.925	partly_thawed
2023-08-05	6	59.7348555	66.1898182	13.0875	partly_thawed
2023-08-06	6	101.669452	107.152667	11.625	partly_thawed
2023-08-07	6	46.415161	51.7328859	11.875	partly_thawed
2023-08-08	6	50.7337198	60.983005	12.0125	partly_thawed
2023-08-09	6	50.8757148	56.5830926	13.8875	partly_thawed
2023-08-10	6	107.105636	111.843301	13.9375	partly_thawed
2023-08-11	6	56.2275049	64.0516535	13.3375	partly_thawed
2023-08-12	6	68.3311498	75.5072875	12.8	partly_thawed
2023-08-13	6	50.7633661	65.6487623	12.75	partly_thawed
2023-08-14	6	105.827707	117.849916	13.2875	partly_thawed
2023-08-15	6	104.659029	117.474173	13.8625	partly_thawed
2023-08-16	6	90.186093	111.175356	13.4	partly_thawed
2023-08-17	6	53.6937611	57.1817659	12.8875	partly_thawed
2023-08-18	6	68.4988103	94.2451418	12.1875	partly_thawed
2023-08-19	6	83.7797336	105.58579	11.8	partly_thawed
2023-08-20	6	65.4200639	73.8287304	11.975	partly_thawed
2023-08-21	6	86.6755397	98.7066985	13.1	partly_thawed
2023-08-22	6	101.218752	127.663228	13.7	partly_thawed
2023-08-23	6	105.18271	144.897213	13.9125	partly_thawed
2023-08-24	6	110.510497	142.388473	12.9	partly_thawed
2023-08-25	6	101.360275	101.964527	12.1375	partly_thawed
2023-08-26	6	110.248594	104.11099	12.1125	partly_thawed

2023-08-27	6	69.1696216	91.9143423	11.6375	partly_thawed
2023-08-28	6	63.0693781	67.8501806	12.025	partly_thawed
2023-08-29	6	97.0584329	114.239248	12.45	partly_thawed
2023-08-30	6	116.592803	122.524322	13	partly_thawed
2023-05-19	7	49.334863	47.8621745	2.0125	fully_thawed
2023-05-20	7	46.9200393	44.4316941	2.1	fully_thawed
2023-05-21	7	52.0751732	52.4462877	2.425	fully_thawed
2023-05-22	7	75.3469779	77.2452609	2.275	fully_thawed
2023-05-23	7	44.6685192	47.9344752	2.975	fully_thawed
2023-05-24	7	33.8936121	42.0889037	2.8375	fully_thawed
2023-05-25	7	37.6489882	40.4435532	2.75	fully_thawed
2023-05-26	7	34.7523409	36.5482176	2.55	fully_thawed
2023-05-27	7	39.9671258	38.7382302	2.4875	fully_thawed
2023-05-28	7	39.3415505	39.2518293	3.35	fully_thawed
2023-05-29	7	34.1545325	34.2216868	3.2875	fully_thawed
2023-05-30	7	36.1480781	41.6197173	3.15	fully_thawed
2023-05-31	7	31.5812416	39.6837059	3.2625	fully_thawed
2023-06-01	7	34.2491326	39.51766	2.75	fully_thawed
2023-06-02	7	36.3974991	44.3509345	3.6625	fully_thawed
2023-06-03	7	36.4606779	35.9005886	4.0125	fully_thawed
2023-06-04	7	33.4537363	33.4941482	4.2375	fully_thawed
2023-06-05	7	30.5260161	32.7818017	4.05	fully_thawed
2023-06-06	7	39.7875148	40.7727151	4.4625	fully_thawed
2023-06-07	7	44.0400964	48.0598024	4.3375	fully_thawed
2023-06-08	7	39.0480798	38.3578566	4.325	fully_thawed
2023-06-09	7	50.2600447	55.2714998	4.4125	fully_thawed
2023-06-10	7	72.8707437	68.8740667	4.2	fully_thawed
2023-06-11	7	54.8621741	66.7493228	4.8625	fully_thawed
2023-06-12	7	46.3315212	46.9956524	5.7625	fully_thawed
2023-06-13	7	46.4795599	46.4291483	5.575	fully_thawed
2023-06-14	7	49.2634297	50.9196366	5.625	fully_thawed
2023-06-15	7	52.4206463	51.1836335	5.95	fully_thawed
2023-06-16	7	74.340552	77.4791259	5.2375	fully_thawed
2023-06-17	7	80.1579366	81.5767077	5	fully_thawed
2023-06-18	7	92.6844436	111.973471	6.0875	fully_thawed
2023-06-19	7	112.902023	111.779864	6.6375	fully_thawed
2023-06-20	7	76.8289006	112.675045	7.7	fully_thawed
2023-06-21	7	103.716188	117.563215	8.55	fully_thawed
2023-06-22	7	64.6615473	66.5804132	7.775	fully_thawed

2023-06-23	7	104.424053	104.192511	8.5375	fully_thawed
2023-06-24	7	91.6352675	97.5669571	7.575	fully_thawed
2023-06-25	7	108.874606	105.322583	7.125	fully_thawed
2023-06-26	7	78.4405403	72.111787	6.7375	fully_thawed
2023-06-27	7	97.4924365	124.258865	7.7375	fully_thawed
2023-06-28	7	138.313482	164.993641	7.825	fully_thawed
2023-06-29	7	150.786801	156.450101	7.25	fully_thawed
2023-06-30	7	82.7247754	96.6420018	7.55	fully_thawed
2023-07-01	7	93.5174097	84.1863838	7.0875	fully_thawed
2023-07-02	7	84.1199896	114.774776	6.3375	fully_thawed
2023-07-03	7	68.8906932	81.4311045	5.2875	fully_thawed
2023-07-04	7	125.311515	128.833645	5.05	fully_thawed
2023-07-05	7	82.7811367	86.2692138	6.4	fully_thawed
2023-07-06	7	115.519992	106.05497	5.775	fully_thawed
2023-07-07	7	83.6127463	94.5363047	6.3875	fully_thawed
2023-07-08	7	117.799471	161.497365	7.1875	fully_thawed
2023-07-09	7	127.258105	154.346676	6.65	fully_thawed
2023-07-10	7	134.356642	153.716332	5.5	fully_thawed
2023-07-11	7	119.822284	127.748772	6.4375	fully_thawed
2023-07-12	7	63.2641997	81.4714608	6.6625	fully_thawed
2023-07-13	7	73.3970921	75.3129335	7.0875	fully_thawed
2023-07-14	7	64.4319988	69.1387471	7.3625	fully_thawed
2023-07-15	7	87.7517355	109.398006	8.0625	fully_thawed
2023-07-16	7	60.0648654	81.7113203	6.5875	fully_thawed
2023-07-17	7	86.8304636	115.092668	6.6875	fully_thawed
2023-07-18	7	91.537164	91.2504492	7.4875	fully_thawed
2023-07-19	7	104.248884	103.742601	7.1375	fully_thawed
2023-07-20	7	96.1184814	106.771965	7.55	fully_thawed
2023-07-21	7	72.9758352	75.4283374	7.9625	fully_thawed
2023-07-22	7	50.8879982	52.5804427	8.0875	fully_thawed
2023-07-23	7	47.890464	51.7904287	8.05	fully_thawed
2023-07-24	7	67.628543	70.1944301	8.025	fully_thawed
2023-07-25	7	66.104418	67.1867027	8.35	fully_thawed
2023-07-26	7	59.0960214	71.3616365	9.45	fully_thawed
2023-07-27	7	107.272419	122.411518	9.2625	fully_thawed
2023-07-28	7	125.58199	131.347129	9.5125	fully_thawed
2023-07-29	7	105.040756	126.584227	10.2875	fully_thawed
2023-07-30	7	71.9771293	84.8288918	9.475	fully_thawed
2023-07-31	7	49.8456284	48.3364605	9.825	fully_thawed

2023-08-01	7	67.1301054	59.9133549	10.2875	fully_thawed
2023-08-02	7	68.0543255	62.641913	9.8	fully_thawed
2023-08-03	7	53.418273	61.6375364	10.625	fully_thawed
2023-08-04	7	89.3546858	110.994566	11.725	fully_thawed
2023-08-05	7	107.694219	110.576869	11.2125	fully_thawed
2023-08-06	7	142.426043	141.600357	9.6875	fully_thawed
2023-08-07	7	59.0778337	62.8037329	10.45	fully_thawed
2023-08-08	7	70.8195516	75.7575534	11.5	fully_thawed
2023-08-09	7	61.1767954	59.970054	13.1625	fully_thawed
2023-08-10	7	122.236264	154.684266	13.15	fully_thawed
2023-08-11	7	76.1331003	77.7675547	12.675	fully_thawed
2023-08-12	7	86.5827151	112.533137	12.4	fully_thawed
2023-08-13	7	87.0160802	106.60389	11.9125	fully_thawed
2023-08-14	7	134.443476	127.821891	12.6625	fully_thawed
2023-08-15	7	177.273142	211.575752	13.0375	fully_thawed
2023-08-16	7	123.484146	131.965013	12.3375	fully_thawed
2023-08-17	7	126.096449	139.218056	12.0875	fully_thawed
2023-08-18	7	171.532134	182.269055	11.15	fully_thawed
2023-08-19	7	103.586558	136.989137	10.425	fully_thawed
2023-08-20	7	76.0763399	73.5902305	11.1875	fully_thawed
2023-08-21	7	89.1069265	106.405968	12.1875	fully_thawed
2023-08-22	7	147.526551	183.595578	12.725	fully_thawed
2023-08-23	7	190.143095	219.501071	12.85	fully_thawed
2023-08-24	7	242.91605	224.040046	11.7375	fully_thawed
2023-08-25	7	112.696976	146.411157	10.7875	fully_thawed
2023-08-26	7	187.9008	182.6657	10.5125	fully_thawed
2023-08-27	7	88.5555957	115.60819	9.9875	fully_thawed
2023-08-28	7	69.6624609	65.0229066	11	fully_thawed
2023-08-29	7	83.0563735	110.917223	11.6625	fully_thawed
2023-08-30	7	198.675869	202.666392	11.9375	fully_thawed
2023-05-19	8	34.7006239	34.6469628	8.8125	fully_thawed
2023-05-20	8	20.7060914	20.4918121	11.5875	fully_thawed
2023-05-21	8	39.7632249	40.1256783	11.55	fully_thawed
2023-05-22	8	51.4766506	51.0077644	12.075	fully_thawed
2023-05-23	8	39.2495605	38.8283208	10.375	fully_thawed
2023-05-24	8	33.4763883	34.4389857	8.775	fully_thawed
2023-05-25	8	21.6617507	30.9194817	6.9	fully_thawed
2023-05-26	8	31.3390259	31.7121132	4.725	fully_thawed
2023-05-27	8	32.3995898	30.6834427	6.7	fully_thawed

2023-05-28	8	19.3751497	20.1882238	10.0375	fully_thawed
2023-05-29	8	20.5861088	25.4842424	7.3375	fully_thawed
2023-05-30	8	37.5520532	34.8199607	6.675	fully_thawed
2023-05-31	8	23.703279	23.7309339	4.125	fully_thawed
2023-06-01	8	24.371716	22.3458104	5.6375	fully_thawed
2023-06-02	8	36.1691973	38.0274175	7.5375	fully_thawed
2023-06-03	8	35.2229112	32.9884145	7.525	fully_thawed
2023-06-04	8	34.5912683	34.2727808	8.1375	fully_thawed
2023-06-05	8	23.7471868	24.6726049	6.825	fully_thawed
2023-06-06	8	34.8645607	37.1863894	11.1875	fully_thawed
2023-06-07	8	51.7544084	47.2871867	10.8125	fully_thawed
2023-06-08	8	30.2154105	29.7787088	9.2125	fully_thawed
2023-06-09	8	55.8270964	58.2682072	18.1	fully_thawed
2023-06-10	8	58.3342632	59.9797712	18.575	fully_thawed
2023-06-11	8	63.8823588	51.5586709	13.3125	fully_thawed
2023-06-12	8	58.3933537	61.3947409	13.075	fully_thawed
2023-06-13	8	42.5780141	43.9541079	14.6625	fully_thawed
2023-06-14	8	38.3218216	38.8987401	16.4875	fully_thawed
2023-06-15	8	42.1898655	41.5978906	12.625	fully_thawed
2023-06-16	8	96.1384255	113.243998	21.425	fully_thawed
2023-06-17	8	97.7764602	97.7908683	21.6875	fully_thawed
2023-06-18	8	115.451319	129.218346	23.0875	fully_thawed
2023-06-19	8	104.867502	107.708625	23.675	fully_thawed
2023-06-20	8	93.700883	95.1999744	20.1375	fully_thawed
2023-06-21	8	86.0736841	92.2739545	18.6375	fully_thawed
2023-06-22	8	64.7044161	66.3194232	21.025	fully_thawed
2023-06-23	8	121.630873	115.917609	15.325	fully_thawed
2023-06-24	8	123.917059	120.159965	14.625	fully_thawed
2023-06-25	8	114.339939	113.91905	15.475	fully_thawed
2023-06-26	8	82.7727499	89.5042756	18.9	fully_thawed
2023-06-27	8	100.223707	109.170843	19.275	fully_thawed
2023-06-28	8	111.760012	123.168416	21.05	fully_thawed
2023-06-29	8	125.297228	136.714036	21.825	fully_thawed
2023-06-30	8	85.4755693	86.0490496	18.5125	fully_thawed
2023-07-01	8	74.3489467	83.5775367	17.4625	fully_thawed
2023-07-02	8	103.054436	106.944953	10.7125	fully_thawed
2023-07-03	8	83.7350237	91.4184859	10.9375	fully_thawed
2023-07-04	8	124.946855	118.949381	18.4125	fully_thawed
2023-07-05	8	89.2157471	89.1379505	11.8875	fully_thawed

2023-07-06	8	101.540381	99.0015504	18.4375	fully_thawed
2023-07-07	8	90.7057301	88.3942528	20.4	fully_thawed
2023-07-08	8	82.0840488	84.6694723	15.85	fully_thawed
2023-07-09	8	99.1335258	94.3421708	20.1125	fully_thawed
2023-07-10	8	103.139045	116.06328	19.025	fully_thawed
2023-07-11	8	91.7801651	85.9948847	20.175	fully_thawed
2023-07-12	8	42.8239454	53.3858829	20.35	fully_thawed
2023-07-13	8	60.9340832	73.6003756	16.7625	fully_thawed
2023-07-14	8	60.0526603	66.8935262	14.575	fully_thawed
2023-07-15	8	76.4054909	83.9482106	14.4625	fully_thawed
2023-07-16	8	45.7691207	46.8267716	13.4125	fully_thawed
2023-07-17	8	88.0293306	85.3056854	15.3375	fully_thawed
2023-07-18	8	79.4695261	73.9802775	16.05	fully_thawed
2023-07-19	8	72.7707008	98.8396103	12.5875	fully_thawed
2023-07-20	8	100.605945	97.1037608	13.6625	fully_thawed
2023-07-21	8	54.6632769	58.9828956	13.4125	fully_thawed
2023-07-22	8	49.1530095	50.0321278	13.55	fully_thawed
2023-07-23	8	52.0787468	52.0586663	14.4375	fully_thawed
2023-07-24	8	55.5108827	77.0189918	15.2375	fully_thawed
2023-07-25	8	55.0531341	75.2777923	15.3125	fully_thawed
2023-07-26	8	80.6270529	90.3159352	16.7	fully_thawed
2023-07-27	8	179.422789	177.185227	20.025	fully_thawed
2023-07-28	8	135.095657	136.476995	20.175	fully_thawed
2023-07-29	8	121.325816	140.213709	19.425	fully_thawed
2023-07-30	8	112.376703	123.029358	16.4625	fully_thawed
2023-07-31	8	65.010212	62.6815346	17.85	fully_thawed
2023-08-01	8	98.6857163	93.9872872	15.55	fully_thawed
2023-08-02	8	98.081123	88.0297787	15.125	fully_thawed
2023-08-03	8	55.3702881	63.9778193	17.075	fully_thawed
2023-08-04	8	114.624674	116.300391	16.5125	fully_thawed
2023-08-05	8	138.729082	138.288381	14.4375	fully_thawed
2023-08-06	8	194.554335	193.395251	14.275	fully_thawed
2023-08-07	8	68.9633448	81.0578537	14.075	fully_thawed
2023-08-08	8	72.2752781	79.3467784	17.675	fully_thawed
2023-08-09	8	73.333636	129.937336	18.3625	fully_thawed
2023-08-10	8	158.331138	159.917908	14	fully_thawed
2023-08-11	8	73.1789191	78.7288633	14.1875	fully_thawed
2023-08-12	8	96.4098046	124.391776	13.925	fully_thawed
2023-08-13	8	74.9828709	135.380888	13.5875	fully_thawed

2023-08-14	8	140.817714	150.033294	15.4625	fully_thawed
2023-08-15	8	249.731429	236.124016	16.4	fully_thawed
2023-08-16	8	151.419455	175.272705	12.3125	fully_thawed
2023-08-17	8	151.557401	179.81294	15.075	fully_thawed
2023-08-18	8	155.843219	193.997706	11.8375	fully_thawed
2023-08-19	8	80.9519732	122.660288	13.675	fully_thawed
2023-08-20	8	62.6858435	70.4797608	15.2375	fully_thawed
2023-08-21	8	84.8247269	210.635347	14.85	fully_thawed
2023-08-22	8	197.024031	212.686385	14.8375	fully_thawed
2023-08-23	8	225.034049	227.98486	14.625	fully_thawed
2023-08-24	8	154.545038	207.369594	13.2625	fully_thawed
2023-08-25	8	100.121819	150.12795	14.1875	fully_thawed
2023-08-26	8	142.596869	154.284122	13.975	fully_thawed
2023-08-27	8	68.0651359	131.91971	13.9625	fully_thawed
2023-08-28	8	61.5780643	61.3165775	13	fully_thawed
2023-08-29	8	89.8932177	111.008369	12.8375	fully_thawed
2023-08-30	8	194.667128	196.736206	14.975	fully_thawed
2023-05-19	9	21.8601571	22.8400082	1.325	fully_thawed
2023-05-20	9	11.6146665	11.0711051	1.3	fully_thawed
2023-05-21	9	18.8943766	17.5897242	1.525	fully_thawed
2023-05-22	9	27.3975222	35.2203079	0.975	fully_thawed
2023-05-23	9	22.424599	24.7424736	1.5125	fully_thawed
2023-05-24	9	12.2903458	27.0290205	1.4875	fully_thawed
2023-05-25	9	20.4846225	18.5515487	1.6625	fully_thawed
2023-05-26	9	18.8217039	17.8283651	1.6875	fully_thawed
2023-05-27	9	29.0562812	28.973108	1.7	fully_thawed
2023-05-28	9	25.1520191	25.883117	1.55	fully_thawed
2023-05-29	9	19.1497958	22.3258512	1.8875	fully_thawed
2023-05-30	9	28.5140197	30.4782789	1.8125	fully_thawed
2023-05-31	9	12.2806488	26.9543911	1.725	fully_thawed
2023-06-01	9	28.7907459	30.7969776	2.0375	fully_thawed
2023-06-02	9	31.7277975	34.5188892	2.85	fully_thawed
2023-06-03	9	12.843581	14.051345	3	fully_thawed
2023-06-04	9	15.4399248	16.8971211	3.025	fully_thawed
2023-06-05	9	10.3431169	8.68856537	2.9125	fully_thawed
2023-06-06	9	17.1475016	17.7663835	3.5	fully_thawed
2023-06-07	9	30.6175896	28.9055717	3.375	fully_thawed
2023-06-08	9	19.1719179	21.2954023	3.0375	fully_thawed
2023-06-09	9	29.2840512	45.483657	3.57142857	fully_thawed

2023-06-10	9	25.4503584	41.9297051	2.75	fully_thawed
2023-06-11	9	28.7861429	42.4575503	2.6	fully_thawed
2023-06-12	9	18.1588137	27.1200648	3.4875	fully_thawed
2023-06-13	9	15.6149258	19.7926886	3.3375	fully_thawed
2023-06-14	9	20.2457051	20.3574749	3.1375	fully_thawed
2023-06-15	9	24.7602037	23.8131516	3.125	fully_thawed
2023-06-16	9	36.6875552	43.5213909	2.9875	fully_thawed
2023-06-17	9	43.4093611	54.1996233	1.7	fully_thawed
2023-06-18	9	33.2430488	79.997975	1.5125	fully_thawed
2023-06-19	9	53.2388994	67.303491	1.4875	fully_thawed
2023-06-20	9	35.0823231	46.0291915	1.7375	fully_thawed
2023-06-21	9	44.3443703	50.4739139	2.8375	fully_thawed
2023-06-22	9	24.7112247	30.5857029	1.7875	fully_thawed
2023-06-23	9	66.3432432	75.0238727	3.775	fully_thawed
2023-06-24	9	71.9940645	68.0269518	3.9125	fully_thawed
2023-06-25	9	66.9624634	69.5681375	4.4	fully_thawed
2023-06-26	9	34.4875342	37.4454253	3.7	fully_thawed
2023-06-27	9	32.1128129	49.3668859	2.55	fully_thawed
2023-06-28	9	35.4868038	70.5200094	3.7375	fully_thawed
2023-06-29	9	56.0230485	66.4854346	2.8	fully_thawed
2023-06-30	9	35.0536483	37.9166821	3.7625	fully_thawed
2023-07-01	9	36.3572308	34.5227723	2.875	fully_thawed
2023-07-02	9	62.9398655	70.2667796	4.3125	fully_thawed
2023-07-03	9	43.9137521	62.711237	3.95	fully_thawed
2023-07-04	9	84.1333927	112.883854	2.7625	fully_thawed
2023-07-05	9	74.1425748	69.6787019	4.875	fully_thawed
2023-07-06	9	55.6372893	60.342801	3.75	fully_thawed
2023-07-07	9	54.1536993	63.6827046	2.75	fully_thawed
2023-07-08	9	57.1462326	111.17401	5.0625	fully_thawed
2023-07-09	9	84.4408589	114.402167	3.9375	fully_thawed
2023-07-10	9	125.758643	202.354261	3.7875	fully_thawed
2023-07-11	9	90.4711308	145.271263	4.3375	fully_thawed
2023-07-12	9	49.3281588	48.1279533	3.7875	fully_thawed
2023-07-13	9	67.5695327	70.2440776	4.5625	fully_thawed
2023-07-14	9	64.166318	99.5091083	5.9125	fully_thawed
2023-07-15	9	83.0417302	110.576682	7.2125	fully_thawed
2023-07-16	9	55.9762745	109.767193	6.0125	fully_thawed
2023-07-17	9	116.356878	129.690126	6.15	fully_thawed
2023-07-18	9	79.6578928	85.2373324	7.9875	fully_thawed

2023-07-19	9	96.2904357	110.851157	8.075	fully_thawed
2023-07-20	9	94.3315022	145.789704	7.9125	fully_thawed
2023-07-21	9	77.8990507	74.6335483	8.8625	fully_thawed
2023-07-22	9	72.2680472	63.7881582	8.975	fully_thawed
2023-07-23	9	65.4965943	64.8153473	8.4875	fully_thawed
2023-07-24	9	75.7396548	88.8207036	8.775	fully_thawed
2023-07-25	9	67.8346061	63.1338917	9.3	fully_thawed
2023-07-26	9	97.3968974	151.103139	9.3875	fully_thawed
2023-07-27	9	191.247927	185.297682	9.625	fully_thawed
2023-07-28	9	193.206865	171.693767	10.2	fully_thawed
2023-07-29	9	92.986422	120.613128	11.225	fully_thawed
2023-07-30	9	117.88812	117.570781	10.85	fully_thawed
2023-07-31	9	83.9161709	76.4805586	10.675	fully_thawed
2023-08-01	9	91.1760178	96.5148396	11.0125	fully_thawed
2023-08-02	9	123.072066	122.536646	11.5	fully_thawed
2023-08-03	9	96.5049759	91.5312138	11.6625	fully_thawed
2023-08-04	9	116.419955	113.372383	12.7875	fully_thawed
2023-08-05	9	102.427354	141.310221	12.9125	fully_thawed
2023-08-06	9	239.310565	229.744061	12.075	fully_thawed
2023-08-07	9	94.2441887	109.598875	12.2	fully_thawed
2023-08-08	9	88.0675217	83.2518536	10.9375	fully_thawed
2023-08-09	9	104.1454	107.21431	12.575	fully_thawed
2023-08-10	9	202.513157	176.289944	13.4125	fully_thawed
2023-08-11	9	109.054042	117.815556	13.1625	fully_thawed
2023-08-12	9	100.641251	146.806711	12.4125	fully_thawed
2023-08-13	9	90.3502941	126.836101	12.5875	fully_thawed
2023-08-14	9	118.76462	188.582827	12.375	fully_thawed
2023-08-15	9	268.856306	254.511493	12.7125	fully_thawed
2023-08-16	9	233.716298	315.282061	12.6125	fully_thawed
2023-08-17	9	153.002257	205.716302	12.3625	fully_thawed
2023-08-18	9	161.186907	178.491091	12.15	fully_thawed
2023-08-19	9	205.850834	193.125026	11.525	fully_thawed
2023-08-20	9	115.506318	140.382822	11.225	fully_thawed
2023-08-21	9	156.318628	270.920632	11.6875	fully_thawed
2023-08-22	9	285.042443	310.843272	12.4875	fully_thawed
2023-08-23	9	273.472399	358.147244	12.6	fully_thawed
2023-08-24	9	146.866361	232.216088	11.95	fully_thawed
2023-08-25	9	132.775318	168.704937	11.375	fully_thawed
2023-08-26	9	244.950784	252.266715	11.2125	fully_thawed

2023-08-27	9	160.286048	152.657018	11.1125	fully_thawed
2023-08-28	9	95.1710018	100.324303	10.8375	fully_thawed
2023-08-29	9	164.601244	235.245973	11.4125	fully_thawed
2023-08-30	9	375.879582	372.361953	11.6375	fully_thawed

770 **Table C5: Results of generalized additive models (GAM) used for determining CH₄ flux season values. Note: Intact 2 plot GAM $R^2_{adj} < 0.1$, and the CH₄ flux periods are based on moving 7-day medians. CI = 95% confidence interval.**

Chamber	R^2_{adj}	p-value	CH ₄ flux period	CH ₄ flux period value (mg CH ₄ m ⁻² d ⁻¹)	95% CI	CH ₄ flux period date (YYYY-MM-DD)
Intact 1	0.32	<0.001	Early	-0.1	-0.6 - 0.3	2023-05-19
			Middle	0.4	0.2 - 0.6	2023-08-16
			Peak	1.2	0.7 - 1.9	2023-08-30
Intact 2	-	-	Early	0.3	-	2023-05-19
			Middle	0.4	-	2023-07-06
			Peak	1.0	-	2023-08-15
Intact 3	0.85	<0.001	Early	5.8	3.8 - 8.9	2023-06-25
			Middle	29.9	19.6 - 45.4	2023-07-26
			Peak	56.8	36.7 - 88.1	2023-08-25
Partly thawed 1	0.76	<0.001	Early	9.8	7.9 - 12.0	2023-06-16
			Middle	32.8	26.6 - 40.4	2023-07-16
			Peak	61.5	41.1 - 91.8	2023-08-30
Partly thawed 2	0.82	<0.001	Early	20.4	17.8 - 23.4	2023-06-23
			Middle	53.4	46.4 - 61.4	2023-08-08
			Peak	92.9	71.5 - 120.8	2023-08-30
Partly thawed 3	0.67	<0.001	Early	22.0	19.9 - 24.4	2023-06-13
			Middle	54.6	49.7 - 60.1	2023-08-01
			Peak	93.5	80.4 - 108.7	2023-08-30
Fully thawed 1	0.66	<0.001	Early	50.6	38.9 - 66.0	2023-05-19
			Middle	85.0	73.8 - 97.8	2023-06-21
			Peak	127.5	109.5 - 148.4	2023-08-25
Fully thawed 2	0.66	<0.001	Early	40.1	33.9 - 47.3	2023-06-07
			Middle	77.7	65.9 - 91.6	2023-06-18
			Peak	120.2	101.0 - 142.9	2023-08-20
Fully thawed 3	0.83	<0.001	Early	35.4	32.3 - 38.9	2023-06-19
			Middle	116.9	106.3 - 128.5	2023-08-04
			Peak	214.4	180.0 - 255.2	2023-08-30

Data availability

The belowground trait and vegetation survey data together with edaphic variables (Määttä and Malhotra, 2026) can be openly accessed at <https://doi.org/10.5281/zenodo.18269229>. The porewater CH₄ and $\delta^{13}\text{C}$ data (Wilson et al., 2026) is available with

775 open access at <https://doi.org/10.5281/zenodo.18363867>. The daily-aggregated automated chamber CH₄ flux data from the productive season and the peat moisture data are shown in the Appendices (Table C5 and Table C3, respectively). The full chamber CH₄ flux dataset will be published in the EMERGE-DB database (Bolduc et al., 2020) by May 2026.

Code availability

780

The R code used for data processing and analysis can be accessed via Zenodo (<https://doi.org/10.5281/zenodo.20718440>; Määttä, 2026).

Author contributions

785 TM and AM conceptualized the study and prepared the original manuscript draft. Data curation and provision of resources was done by TM, RV, PC, SH, RW, SB, and JC. TM conducted the formal analysis, investigation, and visualization, and collected and processed the belowground trait data. Chamber CH₄ flux data was collected and provided by RV and PC, and porewater gas data by SH, SB, RW and JC. AM and TM acquired funding for the study and coordinated the project. AM supervised the project. All authors contributed to the review and editing of the manuscript.

Competing interests

790 The authors declare that they have no conflict of interest.

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