Permafrost melt seep patches increase heterogeneity of soil geochemistry and therefore habitat suitability

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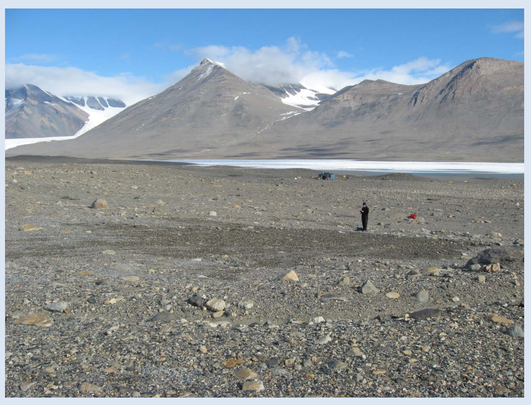
Introduction:

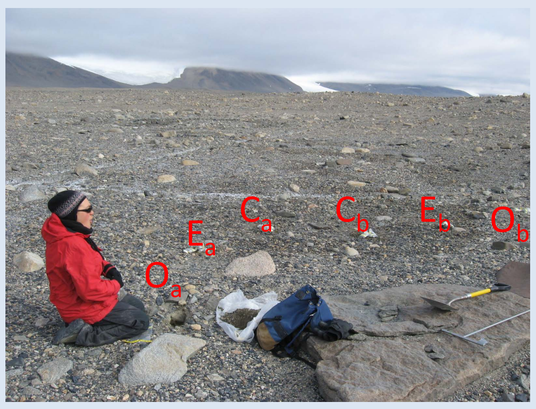
The McMurdo Dry Valleys, a polar desert region in Antarctica, are among the coldest and driest terrestrial habitats on Earth. The prevalence of environmental constraints on soil biology make the dry valleys are climate-sensitive system, where warmer temperatures result in increased availability of liquid water and redistribution of soil salts, with consequences for biological communities and biogeochemical cycling. In recent decades, the dry valleys have experienced periodic discrete warm climate events, characterized by above-average summer temperatures that result in melt water pulses from dry valley ice reserves. During warm events, water from the melt of the ice-cemented permafrost, is drawn through the active layer to the surface by capillary action, causing the appearance of variably-sized wetted patches scattered across the landscape. The impact of these patches on soil biology and the ecological processes dictated by their activity are not yet known.



Example of a permafrost melt seep patch in the Lake Fryxell Basin, Taylor Valley, Antarctica

Objective & Hypothesis:

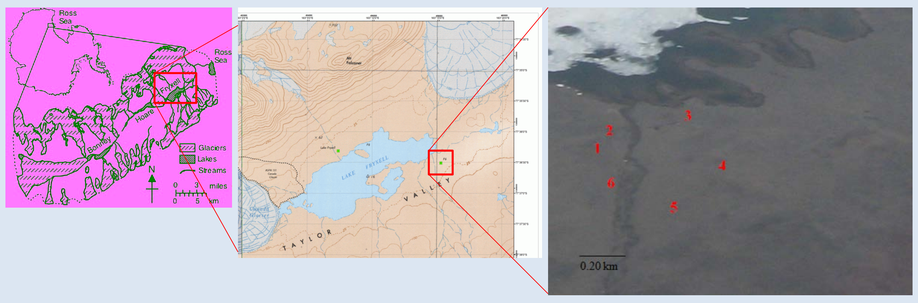
To investigate the consequences of permafrost seep patch appearance on soil geochemistry and biological activity, we sampled seep patches across one lake basin during a discrete warm year. We hypothesized that soils affected by meltwater seeps would be higher in salt content and moisture than the surrounding dry soils outside the seep patch, thereby causing a decrease in biological activity.



Seep patch sampling:
Soil pits dug at three positions (Center, Edge, Outside) along two transects (a, b)

Methods:

Site: Lake Fryxell basin, Taylor Valley, McMurdo Dry Valleys, Antarctica



Sample Collection:

- We sampled 6 permafrost melt seep patches that varied in size.
- 2 transects were established in each patch.
- 3 positions were sampled along each transect:
  Center (C), Edge (E), and Outside (O).
- At each position, a soil samples were taken at 5 depths:
  0-2 cm (1), 2-5 cm (2), 5-10 cm (3), 10-25 cm (4), and 25 cm–D.O.R. (5)

Soil Analyses:

- Soil water content (SWC) - oven drying
- Soil pH and conductivity (EC) - 1:2 and 1:5 soil:water solutions, respectively, measured using senor probes
- Soluble ions -1:5 soil:water extractions measured via ion chromatograph (anions) and ICP-OES (cations)

Respiration Incubations:

- Surface soil samples (0-2 cm) from each C and O position incubated in sealed Exetainer glass vials.
- Vials were flushed with CO_2-free air and incubated at room temperature.
- After 48 h, a 5-ml gas sample was removed and injected into a LI-COR 6262 to measure CO_2 concentration and subsequently calculate C mineralization rate.
- Flushing and measuring of gas samples was repeated every 48 h for a total of 5 measurements over 10 d.

An example of a seep patch at the center (C) of a seep patch

Results:

	Position	Depth	Patch
Fl	NA	NA	NA
Br	NA	NA	NA
Cl	O E C	5 4 3 2 1	6 4 5 1 3 2
NO_3	O E C	5 4 3 2 1	5 6 4 1 2 3
SO_4	O E C	5 4 3 2 1	5 6 4 3 2 1
PO_4	NA	NA	NA
Ca	O E C	4 5 3 2 1	6 4 5 1 2 3
Li	NA	NA	NA
Na	O C E	5 4 3 2 1	4 6 5 3 2 1
K	O E C	5 4 3 2 1	6 4 5 2 3 1
Mg	O E C	4 5 3 2 1	6 4 5 1 3 2
EC	O E C	5 4 3 2 1	4 6 5 3 1 2
pH	E C O	5 1 4 2 3	3 5 4 2 1 6
SWC	O E C	1 2 3 4 5	2 3 6 4 1 5

Table 1. Most ions measured, as well as SWC, EC, and pH, were significantly influenced by position along the transects. *Post hoc* Tukey HSD tests show that, for most measurements, the center and edge locations were similar and significantly higher than outside the patch. This effect of position is true across the patches, despite the fact that the six patches significantly differed from one another in terms of ion content. Ion content also varied significantly with depth in the soil profile. This is due to much lower ion content at the lower depths than at the surface, regardless of position.

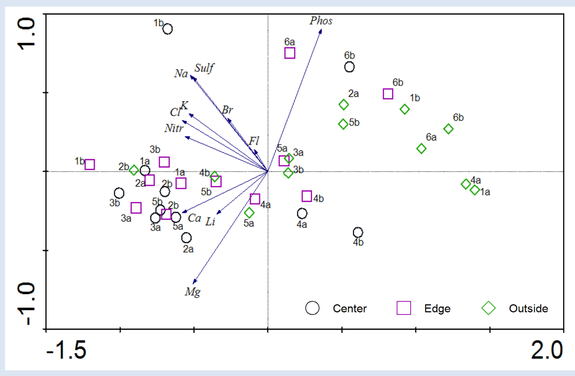


Figure 1. Principal Components Analysis of 0-2 cm samples demonstrates that, at the surface, ion content at the center and edge locations were similar and significantly higher than outside the patch, where ion content is much more variable.

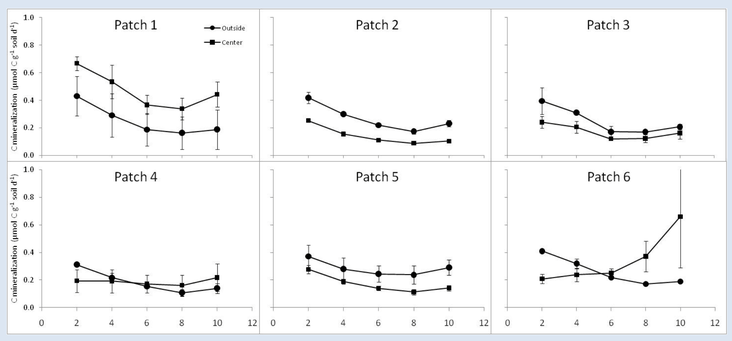


Figure 2. Soil respiration was significantly influenced by patch and position, and how these factors influenced respiration varied over time (Position*Patch*Day $P<0.001$). Specifically, respiration was not consistently higher inside or outside of patches throughout the incubation.

Discussion:

- The presence of permafrost meltwater seep patches increased soil moisture and salt content, particularly at the soil surface.

- Future climate projections suggest that continental Antarctica will begin to exhibit climate warming trends in step with the global warming over the next 50-100 years, and the characteristics of these permafrost seep patches may become a more prevalent feature of the dry valley soil landscape.

- Though the presence of permafrost melt seeps tends to push surface soils to more locally homogeneity consisting of high-ion content, seep patches will differ greatly from the neighboring dry soil, resulting in an increase in landscape-scale heterogeneity by mobilizing those salts from the permafrost and delivering them to the active layer.

- The respiration measurements reveals that seep patches have variable influence on biological activity, with both increases and decreases in respiration observed. The soil from outside all six patches behaved roughly the same. It's the center locations that varied strongly with patch.

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