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Earth's Future

RESEARCH ARTICLE
10.1029/2023EF004306

Response of a Terrestrial Polar Ecosystem to the March 2022 Antarctic Weather Anomaly

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Key Points:

- An atmospheric river caused extreme weather in the Antarctic Dry Valleys in March 2022 with temperatures 25°C above average conditions
- Record fall temperatures drove mobilization of liquid water and reactivation of biota at a time when organisms are entering winter dormancy
- Biotic responses to unseasonable warm and wet conditions may influence diversity and life-history characteristics of biotic communities

Supporting Information:

Supporting Information may be found in the online version of this article.

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Citation:

Barrett, J. E., Adams, B. J., Doran, P. T., Dugan, H. A., Myers, K. F., Salvatore, M. R., et al. (2024). Response of a terrestrial polar ecosystem to the March 2022 Antarctic weather anomaly. *Earth's Future*, *12*, e2023EF004306. https://doi.org/10.1029/2023EF004306

Received 27 NOV 2023
Accepted 26 APR 2024

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Funding acquisition: J. E. Barrett, Byron J. Adams, Peter T. Doran, Hilary A. Dugan, Mark R. Salvatore, Michael N. Gooseff

Abstract Record high temperatures were documented in the McMurdo Dry Valleys, Antarctica, on 18 March 2022, exceeding average temperatures for that day by nearly 30°C. Satellite imagery and stream gage measurements indicate that surface wetting coincided with this warming more than 2 months after peak summer thaw and likely exceeded thresholds for rehydration and activation of resident organisms that typically survive the cold and dry conditions of the polar fall in a freeze-dried state. This weather event is notable in both the timing and magnitude of the warming and wetting when temperatures exceeded 0°C at a time when biological communities and streams have typically entered a persistent frozen state. Such events may be a harbinger of future climate conditions characterized by warmer temperatures and greater thaw in this region of Antarctica, which could influence the distribution, activity, and abundance of sentinel taxa. Here we describe the ecosystem responses to this weather anomaly reporting on meteorological and hydrological measurements across the region and on later biological observations from Canada Stream, one of the most diverse and productive ecosystems within the McMurdo Dry Valleys.

Plain Language Summary An atmospheric river event in March 2022 led to record warm temperatures over much of Antarctica. Here we report the ecological and hydrological responses to these extraordinary temperatures. The McMurdo Dry Valleys are unique among other regions of Antarctica that experienced this extreme weather event because contemporary observations of ecosystem responses to unseasonable weather can be anchored to a 30-year record of meteorology, stream flow, and soil community data supported by the National Science Foundation Long Term Ecological Research program. As such weather anomalies are expected to be more common in future Antarctic climate regimes our insights are broadly relevant to the scientific community seeking to predict future ecosystem and organismal responses to ongoing climate change.

1. Introduction

Climate change is contributing to greater frequency of extreme weather (Casson et al., 2019; IPCC, 2022), and Polar Amplification predicts that such events will be especially evident in the Arctic and Antarctic (Biskaborn et al., 2019; Siegert et al., 2023). Polar regions experienced record heat waves in March 2022; in the Arctic, temperatures reached 30°C above average and sea-ice extent was the lowest on record for this typically cold month (Patel, 2022; Vargin et al., 2022). In the Antarctic, record temperatures were documented by multiple research stations on the polar plateau in continental East Antarctica; most notably, Vostok and Concordia stations recorded high temperatures more than 40°C above average conditions on 18 March 2022 (Patel, 2022). This weather anomaly was driven by an intense atmospheric river advecting subtropical heat and moisture deep into the Antarctic interior (Maclennan et al., 2023).

Record high temperatures were also documented in the McMurdo Dry Valleys of Antarctica in the third week of March 2022 (Figure 1). Unlike stations on the polar plateau, this region is a landscape mosaic of glaciers, arid soils, streams, and perennial ice-covered lakes, and is the focus of a U. S. National Science Foundation-supported Long Term Ecological Research (LTER) project that has monitored meteorology, hydrology, and the resident

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organisms and ecosystems for over 30 years (Gooseff et al., 2017). The extreme climate of terrestrial Antarctica limits biodiversity in this region to microbes, including cyanobacterial mats, and a few taxa of invertebrates such as rotifers, tardigrades, and nematodes that survive in a freeze-dried state during the cold and dry conditions that characterize this region (Lee et al., 2019; McKnight et al., 2007). The McMurdo Dry Valleys can thus uniquely illustrate the hydrological and ecological responses to this extreme weather event of March 2022.

Rapid shifts between contrasting weather conditions, such as the occurrence of unseasonable warm events in winter before a return to more typical cold temperatures, or similar variation during seasonal transitions in spring and fall, for example, weather whiplash (Loecke et al., 2017), can challenge biota, especially plants and invertebrates, because of the physiological stress experienced by poikilothermic organisms during freeze-thaw cycles (Knox et al., 2017; Switanek et al., 2017). This may be especially significant in polar regions where the phase change between ice and liquid water is a critical control over terrestrial ecosystems (Casson et al., 2019; Pedersen et al., 2022). In this report we describe the hydrological and ecological significance of the 18 March 2022 Antarctic weather anomaly (Maclennan et al., 2023), focusing on the Canada Stream Antarctic Specially Protected Area #131 (ASPA) in Taylor Valley, an area of active hydrology (McKnight & Tate, 1997) and regionally high floral and faunal diversity (Schwarz et al., 1992, 1993). Here, the responses of microbial mats and soil invertebrates exemplify the potential influence of extreme weather on sentinel taxa for this region. We used remote sensing observations of surface wetting from March 2022 to inform later sample collection for soil invertebrate communities at the first opportunity in December 2022. We hypothesize that extreme and unseasonable weather events will have significant effects on activity, life history, and diversity of resident biota because of the physiological stress associated with freeze-thaw, particularly during critical seasonal transitions.

2. Material and Methods

2.1. Site Description

The McMurdo Dry Valleys (78°S, 162°E) are the largest (4,500 km^2) ice-free area on the Antarctic continent (Levy, 2013) with a landscape comprised of glaciers, exposed soils and rock, ephemeral stream channels, and closed-basin ice-covered lakes (Gooseff et al., 2017). The McMurdo LTER program has reported mean annual air temperature of −19°C, with extreme cold in the winter (<−40°C) and typical temperatures near the melting point of water in the summer months (Obryk et al., 2020). The Canada Stream, which flows into the western end of Lake Fryxell at the terminus of the Canada Glacier in eastern Taylor Valley (McKnight & Tate, 1997) has particular biological significance because of the high moss, cyanobacteria, and invertebrate abundance and diversity (Schwarz et al., 1992, 1993), and high rates of primary productivity (Power et al., 2020; Salvatore et al., 2021).

2.2. Meteorological Observations

Meteorological data were selected from five automated weather stations located in the McMurdo Dry Valleys (Figure 1). Initiation of measurements at these stations varied from 1987 to 2010, but the main weather stations in Taylor and Wright Valleys have an average record length exceeding 30 years. For a detailed description of the frequency and methods of data collection, averaging, storage, and the post-processing of temperature records see Obryk et al. (2020). Mean summer (November–February), March, and average air temperatures at 3 m height for 18 March were calculated from the entire record to 1 May 2022 (Table 1). Additionally, we calculated the standard deviation for 18 March daily temperatures (σ) over the entire record, the difference between the maximum 18 March 2022 and the long-term average 18 March air temperature (δT), and a 18 March 2022 deviation metric was expressed as $\delta T/\sigma$ following the approach of Schar et al. (2004). Exceedance frequency plots of daily maximum air temperature and wind speed were calculated using the long-term meteorological records from Lake Fryxell and Lake Bonney stations. From a 14-day window centered on a given date, exceedance frequency was calculated as the number of days exceeding a given air temperature and wind speed divided by total observations (approximately $n = 427$).

2.3. Stream Hydrological Observations

Stream discharge and water temperature data were collected with CR10x data loggers at the Canada Stream gage in Taylor Valley and the Onyx River at Lower Wright gage in neighboring Wright Valley at 15-min intervals (Wlostowski et al., 2016). Stream stage is measured using Accubar Sutron Corporation pressure transducers.

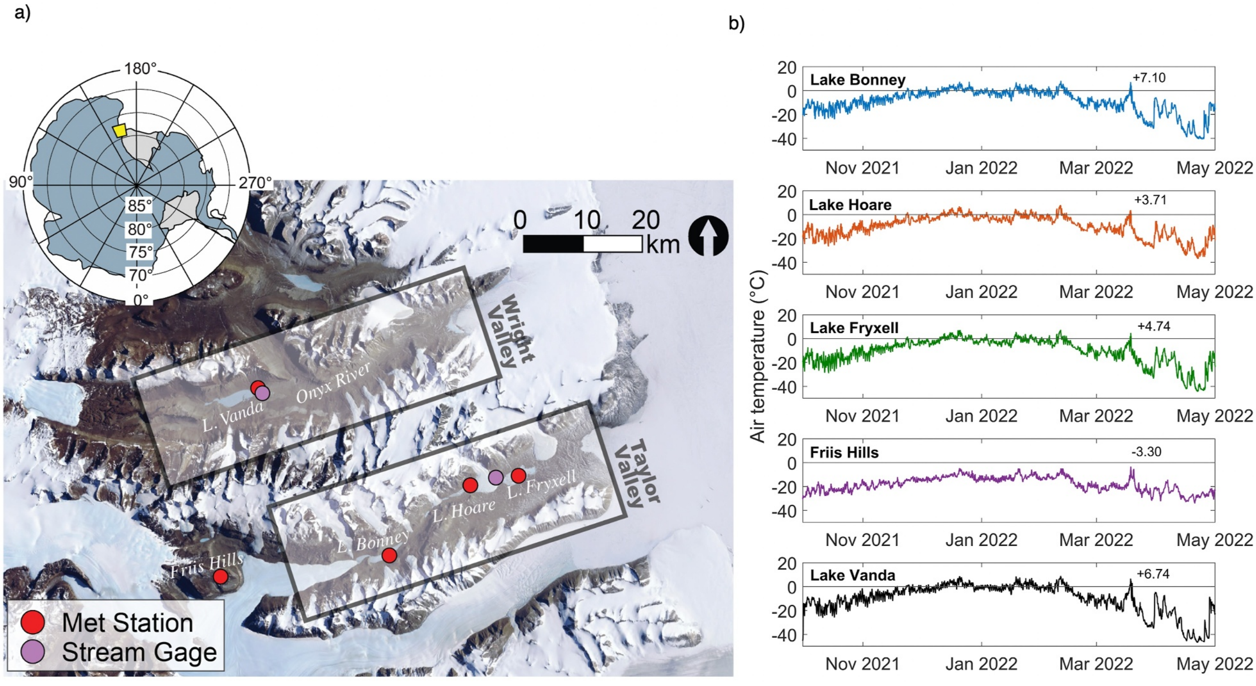

Figure 1. (a) Map of the McMurdo Dry Valleys, Antarctica and (b) the location of meteorological stations where air temperature was recorded at Lake Bonney, Lake Hoare, Lake Fryxell, the Friis Hills, and Lake Vanda.

Discharge data was developed from stage data using a rating curve relationship between stream stage and discharge created in AQUATIC Informatics AQUARIUS timeseries software. Stream temperature is measured using Campbell Scientific CS547A conductivity probes.

2.4. Remote Sensing

We use the methodology of Salvatore et al. (2023) to generate topographically normalized surface albedo products using two WorldView-2 images acquired on 14 March 2022 (10300100CF2E9A00) and 20 March 2022 (10300100CF5E1E00). Assuming no significant changes to the composition of the land surface between these two images, the only two factors that could result in a darkening of the surface are: (a) the introduction of shadows from clouds or surface topography and (b) the addition of water. We used a 1-m lidar-derived digital elevation model (Fountain et al., 2014) to first predict and then remove the influence of topographic shading from the surface albedo products. As there are no clouds or cloud-derived shadows observed in the areas of interest in either image, the only reason to observe darkening of the landscape between the acquisition of these two WorldView-2 images is because of increasing surface soil moisture. Once water content values were derived for all pixels in both images using the lab-derived relationship from Salvatore et al. (2023), the 14 March values were subtracted from the 20 March values to generate an image showing the difference in soil moisture content before and after the 18 March 2022, warming event. These soil moisture predictions were used to inform selection of soil sampling sites for the characterization of soil invertebrate communities in December 2022 (Section 2.4).

We calculated the normalized differential vegetation index (NDVI), as:

$$\text{NDVI} = (\rho\text{NIR} - \rho\text{Red})/(\rho\text{NIR} + \rho\text{Red})$$

where ρNIR and ρRed are the spectral reflectance measurements acquired in the near-infrared 770–895 nm, band 7 and red 630–690 nm, band 5, respectively. NDVI is a common vegetation index used for determining whether an image contains photosynthesizing vegetation and has been successfully used in the Canada Stream area (Power et al., 2020; Salvatore et al., 2021).

Table 1
Mean Daily Summer (NDJF) Air Temperature, Mean Monthly March Air Temperature, Mean Daily 18 March Temperature for the Entire Record and Standard Deviation (σ), Mean Daily 18 March 2022 Air Temperature, Maximum 18 March 2022 Are Temperatures, the Difference Between Maximum and Average 18 March Temperatures (δT) and the Number of Standard Deviations Above the Average Temperatures Experienced on 18 March 2022 (δT/σ) for Meteorological Stations in the McMurdo Dry Valleys (Figure 1) (Doran & Fountain, 2022a, 2022b, 2023a, 2023b, 2023c)

Station	Mean summer temperature (°C)	Mean March temperature (°C)	Mean 18 March temperature (°C)	σ 18 March temperature (°C)	Mean 18 March 2022 temperature (°C)	Maximum 18 March 2022 temp. (°C)	δT	δT/σ	Start of record
LakeBonney	−3.80	−18.88	−19.26	7.38	0.98	7.10	26.36	3.57	24 November 1993
Lake Hoare	−4.97	−18.98	−20.00	5.97	−2.85	3.71	23.71	3.97	11 November 1987
Lake Fryxell	−5.03	−20.47	−20.83	6.44	−4.32	4.74	25.57	3.97	7 December 1993
Friis Hills	−14.19	−22.75	−23.33	5.67	−9.71	−3.30	20.03	3.54	21 December 2010
Lake Vanda	−2.95	−21.35	−22.88	9.13	1.31	6.74	29.62	3.24	24 November 1994
Mean							25.06	3.66	

2.5. Soil Invertebrate Enumeration and Analyses

Three replicate soil samples were collected on 25 December 2022 from 1 m^2 plots at 15 pre-determined GPS coordinates selected from the albedo-surface water model (Section 2.3) to include areas that exhibited significantly elevated surface water content in the 20 March image, areas that did not show significantly elevated surface water content in the 20 March image, and validation sites that were positioned outside of the stream channel and riparian zone. The top 10 cm of soil was collected into a WhirlPak© bag using a trowel. Gravimetric water content of all soils was measured by mass loss after drying at 105°C for 24 hr. Soil invertebrates were extracted from soils using a modified sugar-centrifugation extraction procedure (Freckman & Virginia, 1997) and identified using inverted microscopy. The nematode genera *Eudorylaimus* and *Plectus* include cryptic species that we do not distinguish morphologically (Adams et al., 2006), but recent evidence has confirmed that *Scottnema lindsayae* is a single species within the McMurdo Dry Valley region (Jackson, 2022). A fourth nematode taxa *Geomonhystera antarcticola*, rarely observed in the McMurdo Dry Valleys, has been reported in soils under microbial mats and moss and from sandstone derived soils that host cryptoendolithic communities of cyanobacteria (Adams et al., 2014). Tardigrades, rotifers, and the occasional flatworm are noted and counted but not further identified in routine enumeration.

Mortality was calculated as the ratio of dead to live nematodes and fecundity was calculated as the ratio of live juvenile to live female nematodes identified in sample extractions. Samples with zero observations in the denominator were excluded from analyses. Abundance of live organisms and life history trait data for soil invertebrate communities were analyzed using non-parametric comparisons (e.g., Wilcoxon Rank Sum tests) between the wetted and dry soils, and non-linear regressions over the full range of soil moisture conditions.

3. Results

Air temperatures recorded by McMurdo Dry Valleys LTER automated meteorological stations on 18 March 2022 rose above freezing and exceeded mean temperatures by an average of 25°C and three to four standard deviations of the mean (Table 1). Soil temperatures followed the same temporal trends and reached or exceeded 0°C at the three main Taylor Valley meteorological stations (Figure S1 in Supporting Information S1). The Lake Bonney meteorological station recorded the highest regional temperature of +7.10°C at 14:00 local time on 18 March (Figure 1b). This temperature exceeded the previous high March temperature of +2.82°C recorded at this station in 1996, and the long-term average for March by 26.36°C and 3.57 standard deviations of the mean (Table 1). Air and soil temperatures were also higher than average later in the 2022 autumn, that is, April and May, but did not exceed the 0°C threshold when water can be mobilized and thus biota activated.

Air temperatures above +7°C are unusual in the McMurdo Dry Valleys even during the peak of summer insolation in December and January (Figure 2) and are exceptionally unlikely during the austral fall based on the 30-year records for the Lakes Bonney and Fryxell meteorological stations (Figures 2a and 2b). At the Lake Bonney station, situated close to the Polar Plateau, high temperatures were associated with sustained westerly foehn winds of 10 m s^{-1} through 17 March, and rose to 20 m s^{-1} on 18 March (Figure S3 in Supporting Information S1), a time

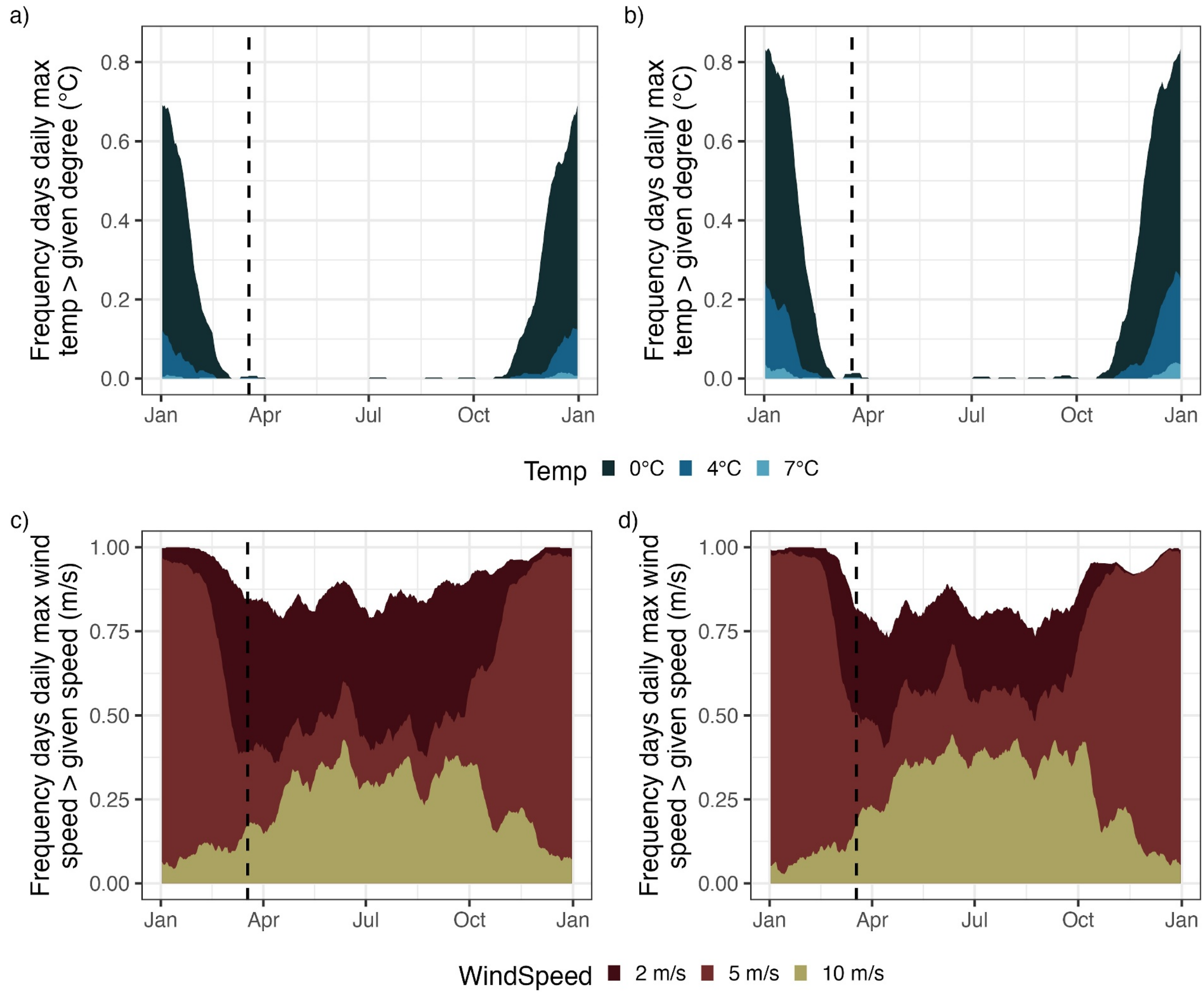

Figure 2. Frequency of daily maximum air temperature exceeding 0, 4, and 7°C during a given 2-week window at (a) Lake Fryxell and (b) Lake Bonney meteorological stations from 1994 to 2022. Frequency of daily maximum wind speed exceeding 2, 5, and 10 m/s during a given 2-week window at (c) Lake Fryxell and (d) Lake Bonney meteorological stations from 1994 to 2022. Dashed line indicates 18 March.

of year when strong wind events are not especially prevalent (Figures 2c and 2d). Notably, there was a transient decrease in temperature coinciding with a 75-min drop in wind speed and change in wind direction, with easterlies prevailing for this range of time, before westerly winds increased again, and temperatures reached their maximum (Figure S3 in Supporting Information S1).

Multispectral satellite imagery shows significant surface darkening in the vicinity of Canada Stream in the Lake Fryxell basin between images acquired on 14 and 20 March 2022 (Figure 3a). Salvatore et al. (2023) have recently developed a model for estimating surface soil moisture from topographically corrected remotely sensed surface albedo in the McMurdo Dry Valleys. This model uses a decade-long image baseline and high-resolution airborne lidar data to quantify the reflectance associated with topographic changes and those associated with surface albedo. In the areas of Canada Stream observed, the average albedo of the pixels from the 14 March image was 95.4% ± 6.5%, within one standard deviation of the long-term median albedo. In contrast, the average albedo of the 20 March image within the region of interest was 75.6% ± 6.7% relative to the long-term median albedo recorded over the last decade. This is more than three times darker than the long-term median albedo. These albedo values correspond to average gravimetric water contents of 0.04 ± 0.03 and 0.09 ± 0.02 on 14 and 20 March, respectively, suggesting at least a doubling of liquid water associated with the 18 March weather anomaly. Microbial mat communities in these wetted areas also exhibited increases in the NDVI between images collected on 14 and 20 March (Figure 3b) when predicted soil moisture content accounted for 30% of the variation in NDVI values (linear regression $r^2 = 0.30$, $p = 0.035$).

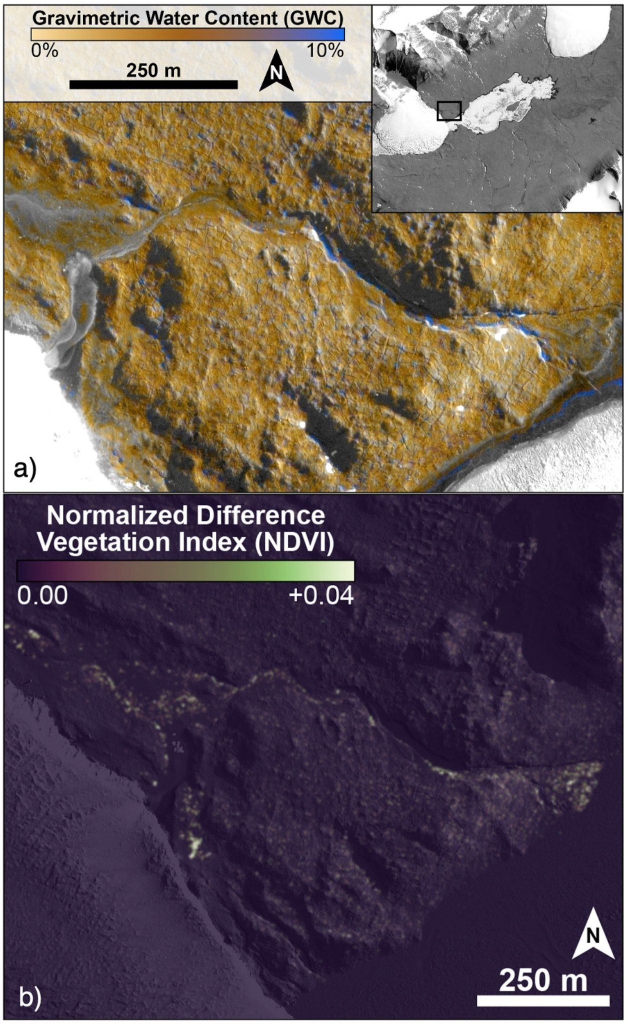

Figure 3. A subset of WorldView-2 image 10300100CF5E1E00 over the Canada Stream of Taylor Valley acquired on 20 March 2022. Both the inset and the primary basemap are panchromatic images, while the colors represent the surface soil moisture content derived from the instrument's visible/near-infrared multispectral capabilities (a). Normalized differential vegetation index from the same image illustrates areas of significant microbial mat spectral activity (b). Imagery © Maxar Technologies.

Stream gages on both the Canada Stream and Onyx River in neighboring Wright Valley recorded temperatures above freezing and increases in stream discharge on 18 March 2022 (Figure 4, Figure S4 in Supporting Information S1). Streamflow in the McMurdo Dry Valleys is dominated by glacial melt, occurring 8–10 weeks per year with no observations of flow outside the summer season. Activation of the Canada Stream in March 2022 is significantly outside the range of the 30-year record for this time of the year (Figure 4a). These stream gage measurements corroborate the interpretation of remotely sensed data and indicate that the Canada Stream experienced significant mobilization of liquid water in surface soils and sediments, resulting in moisture levels of up to 0.15 gravimetric water content.

Invertebrate populations in soils collected on 25 December 2022 (nine months after the event) ranged from zero to over 12,000 individuals per kg soil, generally increasing with measured gravimetric water content (Figure 5a). Invertebrate communities were dominated by the endemic nematode *Scottnema lindsayae* in the driest soils, generally located outside the wetted areas of the 18 March event, where we observed relative abundances of 67%–99% of this species. Soils associated with stream margin sediments, which were moderately wet at the time of collection hosted more even communities consisting of multiple taxa, including rotifers, tardigrades, and the nematode taxa *Eudorylaimus* spp and *Geomonhystera antarcticola* (Figure 5b). Wet sediment invertebrate communities were numerically dominated by additional taxa not observed in the drier environments, that is, the nematode genus *Plectus* and rotifers (Figure 5b). *Scottnema* was the only taxa examined that experienced significant demographic variation between wet and dry sites, with both greater mortality and fecundity in the soils inundated by the 18 March event (Figure S5 in Supporting Information S1).

4. Discussion

Meteorological, satellite, and stream gage data indicate that the McMurdo Dry Valleys experienced a significant and unseasonable warming event on 18 March 2022, generating liquid water in soils and sediments above the threshold required for the rehydration and activation of sentinel taxa. Treonis et al., 2000 reported a moisture threshold for nematodes emerging from an inactive freeze-dried state, that is, anhydrobiosis, of ~0.02 gravimetric water content. Similarly, rapid rehydration and production of microbial mats in a relict stream channel were observed following a reactivation experiment (McKnight et al., 2007). Our multi-spectral albedo model indicates that liquid water content greatly exceeded this water content threshold in the Canada Stream ASPA, and the changes in NDVI and soil invertebrate populations together suggest significant biotic responses to this pulse of liquid water.

Soils in the Canada Stream ASPA host biotic communities with ranges in relative abundances and population densities similar to previous reports within and near riparian zones of streams or lake margins (Ayres et al., 2007; Schwarz et al., 1993). The greatest diversity of soil invertebrates occurred in areas where satellite imagery predicted significant increases in soil moisture between 14 and 20 March 2022 (Figure 5b). However, these same soils also exhibited higher than previous reported mortality for *Scottnema* populations ($p = 0.039$, Figure S5a in Supporting Information S1, Andriuzzi et al., 2018; Barrett et al., 2004). Our observation of >50% mortality is only comparable to results from experimental freeze-thaw treatments where mortality averaged 40% (Knox et al., 2017). This suggests that autumnal wetting and rapid re-freezing may be physiologically challenging to these organisms.

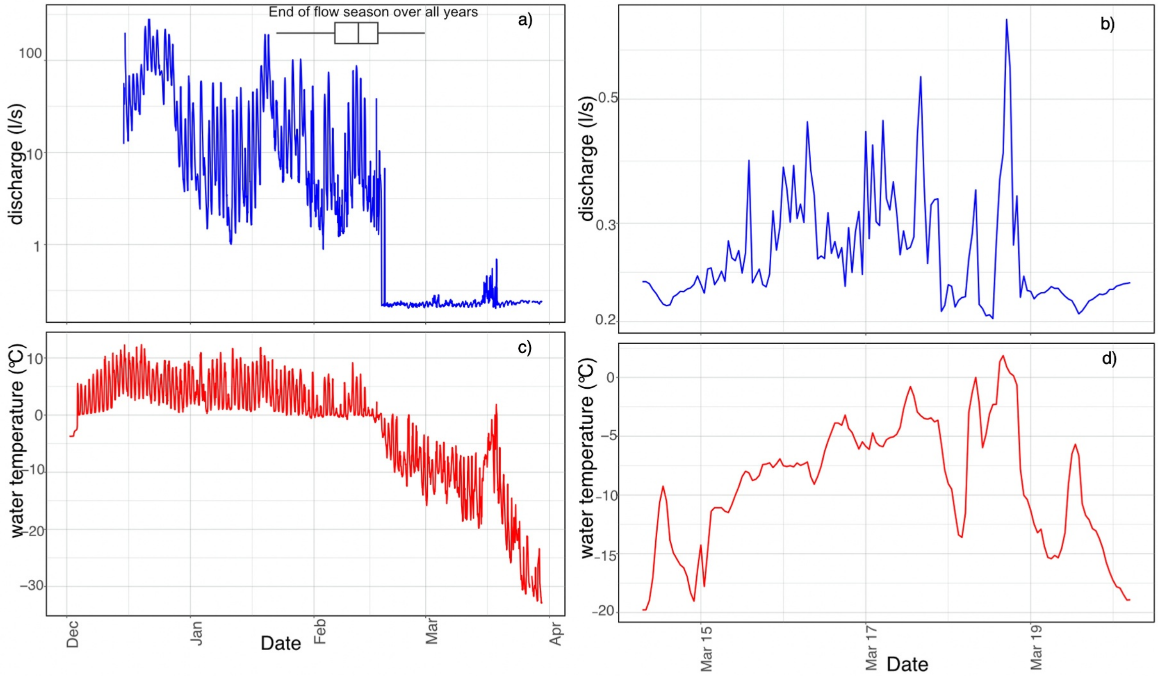

Figure 4. Stream discharge during (a) December 2021 to April 2022, and for (b) 14–20 March 2022, and water temperature for (c) December 2021 to April 2022, and for (d) 14–20 March 2022 for the Canada Stream in Taylor Valley, Antarctica.

Scottnema is a free-living microbial-feeding soil nematode well-adapted to arid soils and is an abundant and widely distributed metazoan throughout continental Antarctica (Adams et al., 2006; Caruso et al., 2019). Late-season rehydration and activation of these soil organisms, followed by rapid re-freeze has a high metabolic cost (Knox et al., 2017) that potentially contributed to the greater mortality observed, but this stress may be offset by higher rates of recruitment in *Scottnema* populations the following summer as indicated by the ratio of juveniles to females ($p = 0.012$, Figure S5b in Supporting Information S1). Previous work has shown that fecundity only exceeds a value of 2 in samples collected during exceptionally warm and wet summers (Andriuzzi et al., 2018; Barrett et al., 2004, 2008, note previously published values were converted from proportional notation to juvenile/female for comparison).

Our interpretation of these trends in life history traits is limited by the temporal lag in the observation of the aseasonable thawing that occurred in March 2022 and sample collection in December 2022. Moreover, the differences between sites that exhibited significant wetting and those that did not are also related to naturally occurring spatial and topographic gradients in water content and biogeochemistry (e.g., Barrett et al., 2009; Treonis et al., 2000). Together these observations support previously published evidence that spatio-temporal variation in hydro-climate is a critical driver of soil community structure, diversity, and activity (Andriuzzi et al., 2018; Barrett et al., 2008; Knox et al., 2017). Further, these results suggest that weather anomalies may influence life-history trade-offs for resident biota, and that activation of these organisms following unseasonable warming and wetting could have important ecological implications for the composition and activity of biotic communities in the McMurdo Dry Valleys.

These high March temperatures and the associated wetting in the McMurdo Dry Valleys are an example of summer-like temperatures suddenly reoccurring in fall, interrupting autumnal cooling and the seasonal transition to winter. Polar night (i.e., 24-hr darkness) begins in early May at this latitude (Figure S2 in Supporting Information S1), but average daily temperatures drop significantly beginning in February and are typically inhospitable to active biology in surface soils and sediments by March (Figure 1). The March 2022 warming occurred during a critical transition time in the hydrological and ecological calendar when temperatures are typically well below freezing but solar radiation is still sufficient to support photosynthesis (Hawes &

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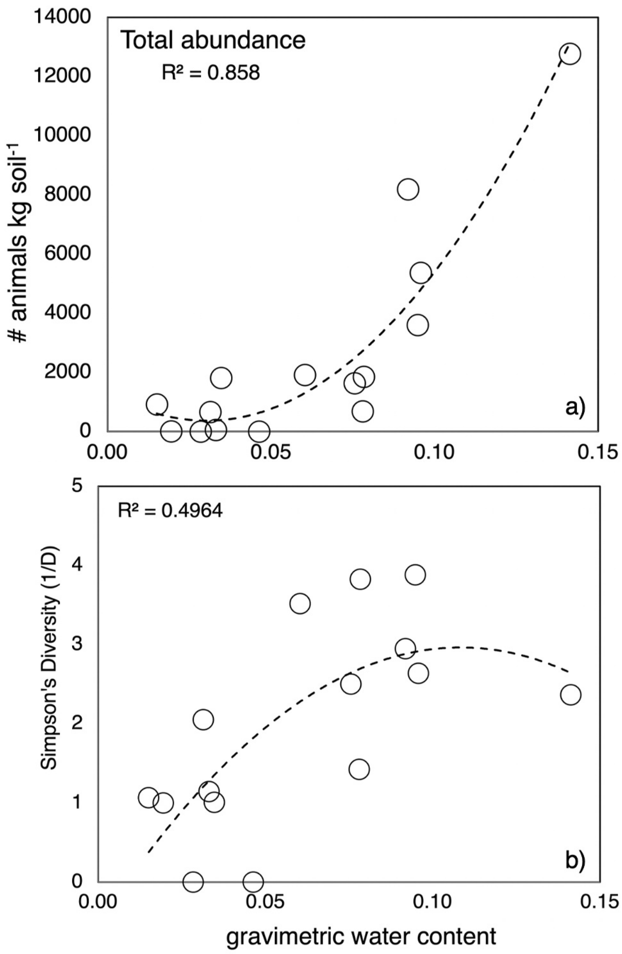

Figure 5. Total abundance (#/kg soil) of nematodes, tardigrades, and rotifers (a) and Simpson's Diversity (b) versus gravimetric water content for soil and sediments collected from the Canada Stream Antarctic Specially Protected Area.

Schwarz, 1999). This contrasts with mid-winter, when air temperatures above freezing do occasionally occur, but PAR is zero (e.g., Figure 2, Figure S2 in Supporting Information S1); a scenario that likely elicits different responses from microbial mat communities. Additionally, the sign of temperature variation matters, as a similar magnitude cooling event in a transitional season may not have any discernible effect on inactive, freeze-dried resident biota. This range of temperature variation and rapid swings in weather conditions may be inherent to the climate regime of this region. For example, in contrast to the record warm March temperatures reported here, Solomon (2001) described how Robert F. Scott's South Pole Party faced unusually cold temperatures in March 1912 that may have contributed to their demise.

Rapid swings in weather can have significant economic, ecological, or hydrological impacts. For example, in temperate climates extremely cold spring temperatures associated with Polar Vortex conditions following mild winters can result in high mortality of deciduous plants and significant economic damage (Casson et al., 2019; Gu et al., 2008; IPCC, 2022). Additionally, drought followed by extreme precipitation (Burt et al., 2018), can alter soil microbial communities and their activity, resulting in mobilization of soil nitrogen and carbon pools (Loecke et al., 2017; Osburn et al., 2021). There are many documented cases of extreme weather events driving ecological responses in the Arctic, (e.g., Christensen et al., 2021; Pedersen et al., 2022), but due to limited human and automated observations, fewer such events have been described in the Antarctic even though the influence of extreme weather on sentinel taxa is expected to be a significant driver of future biodiversity patterns (Siegert et al., 2023). For example, a "flood" event during a record warm summer in 2001/2002 and the responses of terrestrial and aquatic ecosystems has been well documented for the McMurdo Dry Valleys (Gooseff et al., 2017). More recently, rainfall along the Adélie Coast of East Antarctica during the 2013/2014 summer resulted in 100% mortality of the Adélie penguin chick cohort in that region (Ropert-Coudert et al., 2014). Rain was also documented in Taylor Valley in 2018/2019 for the first time (Movie S1 and Table S1 in Supporting Information S1) and climate models predict a future where this may become less exceptional (Maclennan et al., 2022; Vignon et al., 2021). For example, model forecasts predict increased occurrence of atmospheric rivers by the end of the century under mid-warming scenarios (Payne et al., 2020). Atmospheric rivers are associated with enhanced precipitation and the extreme temperatures of East Antarctica in March 2022 (Maclennan et al., 2023). After decades of the McMurdo Dry Valleys not demonstrating significant response to anthropogenic greenhouse warming (Doran et al., 2002; Gooseff et al., 2017) as other regions of Antarctica have (Siegert et al., 2023), the 18 March 2022 weather anomaly may be a portent of future climate with warmer temperatures and greater thaw, characteristics of a changing climate regime in this region of Antarctica and new drivers of organismal and ecosystem dynamics.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

As part of the requirements of the National Science Foundation's Long Term Ecological Research Program and reflecting our own commitment to open and discoverable data our data are accessible through the Environmental Data Initiative (Doran & Fountain, 2022a, 2022b, 2023a, 2023b, 2023c).

Acknowledgments

This work was supported by the National Science Foundation (Grants 2046260, 1744785, 1637708, and 1027284) and Antarctic Support Associates, Leidos. We also thanks Laura Smarrito for the video evidence of recent rain in the McMurdo Dry Valleys.

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