Influence of regional climate on the threatened Haller's Apple Moss (*Bartramia halleriana*) microclimate

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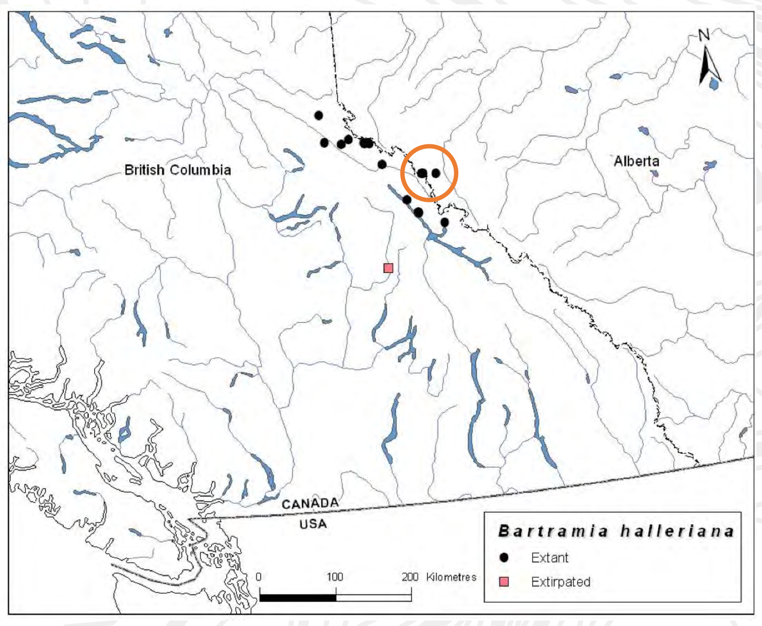
1. Introduction

Many bryophytes grow in highly restricted microhabitats that are characterized by a specific microclimate. Understanding how these microclimate conditions are influenced by regional climate may determine a species' response to climatic extremes and climate change. We examined the capacity for microhabitats to moderate regional climate for the threatened Haller's Apple Moss (*Bartramia halleriana*). In North America, Haller's Apple Moss is currently known from 15 subpopulations, where it grows on forested, non-calcareous rock outcrops along the main ranges of the Rocky Mountains in AB (Jasper National Park) and adjacent BC[1,2]. *The goal of the study was to characterize Haller's Apple Moss microclimate and examine how it relates to both local and regional climate.*

Haller's Apple Moss, Jasper National Park (photo: Richard Caners).



Distribution of the 15 Haller's Apple Moss subpopulations in Canada[2]. Circled subpopulations were used for this study..

2. Study area

Our study includes 8 Haller's Apple Moss sites in Jasper National Park, AB, and 3 sites in Mount Robson Provincial Park, BC. Sites are associated with 3 previously-defined subpopulations for the species[1,2].

Subpopulation name	Park	Province	Study site
Jasper Meadow Creek	Jasper National Park	Alberta	Meadow Creek
Jasper West Gate	Jasper National Park	Alberta	Portal Lake 1
			Portal Lake cutline
			Portal Lake entrance
			Yahoo Hill 1
			Yahoo Hill 2
			Yahoo Hill 3
			Yahoo Hill 4
Fitzwilliam Spur	Mount Robson Provincial Park	British Columbia	Fitzwilliam Spur 1
			Fitzwilliam Spur 2
			Fitzwilliam Spur 3

3. Methods

We used Maxim Integrated DS1923 iButton sensors to measure hourly temperature and humidity from 15 Jun – 25 Sep, 2019. At each site, we placed sensors in 3 microhabitats:

i. among colonies of Haller's Apple Moss on rock outcrops (**subpopulation**)
ii. on the rock outcrop where Haller's Apple Moss was absent (**unoccupied**)
iii. forest understory adjacent to Haller's Apple Moss (**subcanopy**)

Comparable data were obtained from a nearby meteorological station (**region**)[3].

Left—Subpopulation sensor placed among colonies of Haller's Apple Moss on rock outcrop.
Middle—Unoccupied habitat sensor on same rock outcrop but where Haller's Apple Moss was absent.
Right—Subcanopy sensor in understory adjacent to Haller's Apple Moss.

Microclimate variables calculated from sensors are expressed as daily means. Relative humidity was converted to vapour pressure deficit (VPD)[4]. Growing degree days (GDD) use a base temperature of 0°C and represent the total for the growing season. Canopy cover was measured by convex spherical densitometer.

Calculated variables: min temp (°C, minT), max temp (°C, maxT), mean temp (°C, meanT), range temp (°C, rangeT), min VPD (Pa, minVPD), max VPD (Pa, maxVPD), mean VPD (Pa, meanVPD), range VPD (Pa, rangeVPD), total GDD >0°C (GDD0).

Analyses performed in R 3.6.3. **Principal component analysis** (PCA) relates measured microclimate variables and sensor locations (*devtools*, *ggbiplot*). Spearman **correlation matrix** relates microclimate variables and forest canopy cover (*ggcorrplot*). **Box plots** illustrate differences in OLS regression slopes[5] that were measured between the region and sensor locations for maxVPD (*dplyr*, *ggplot2*). Slopes were calculated separately for each site using all data points for the growing season.

4. Results

Haller's Apple Moss microclimate was significantly different from regional climate. Microclimate was generally cooler, more humid, and more stable than the region or other sensor locations (**Fig. 1**). Forest canopy moderated the effects of regional climate at Haller's Apple Moss sites. Canopy cover was negatively related to understory maxT, rangeT, and GDD0, and positively related to minT (**Fig. 2**).

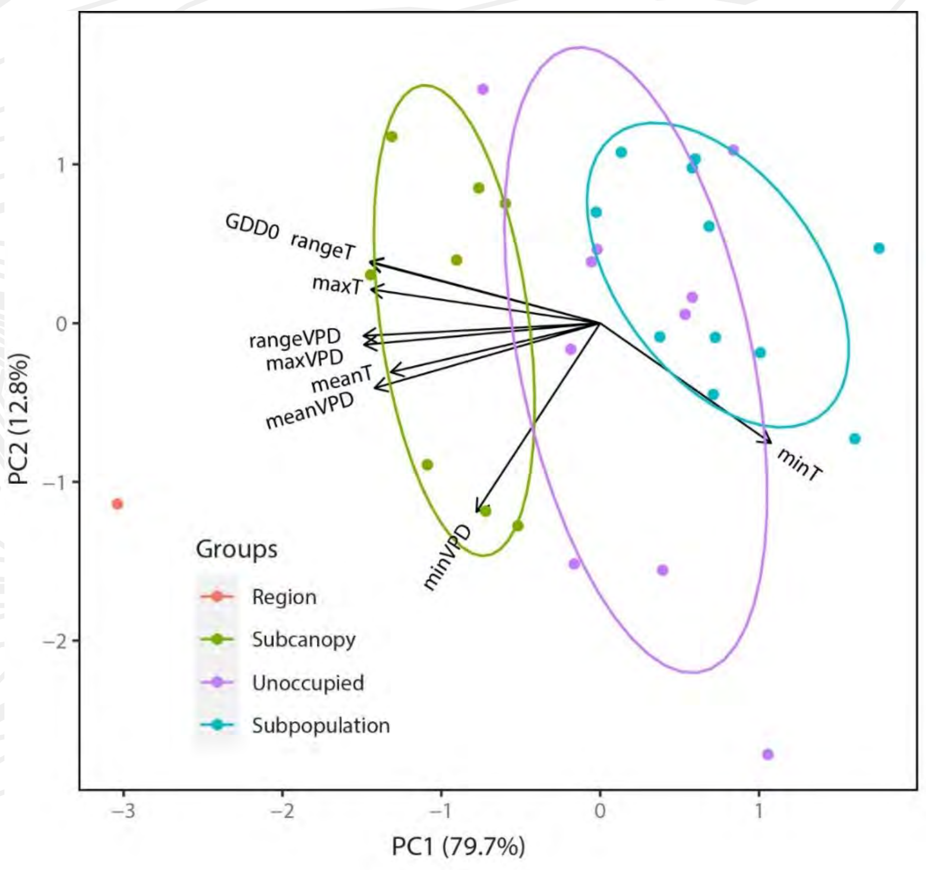


Fig. 1. PCA of measured microclimate variables and sensor locations. Ellipses are 68% CI.

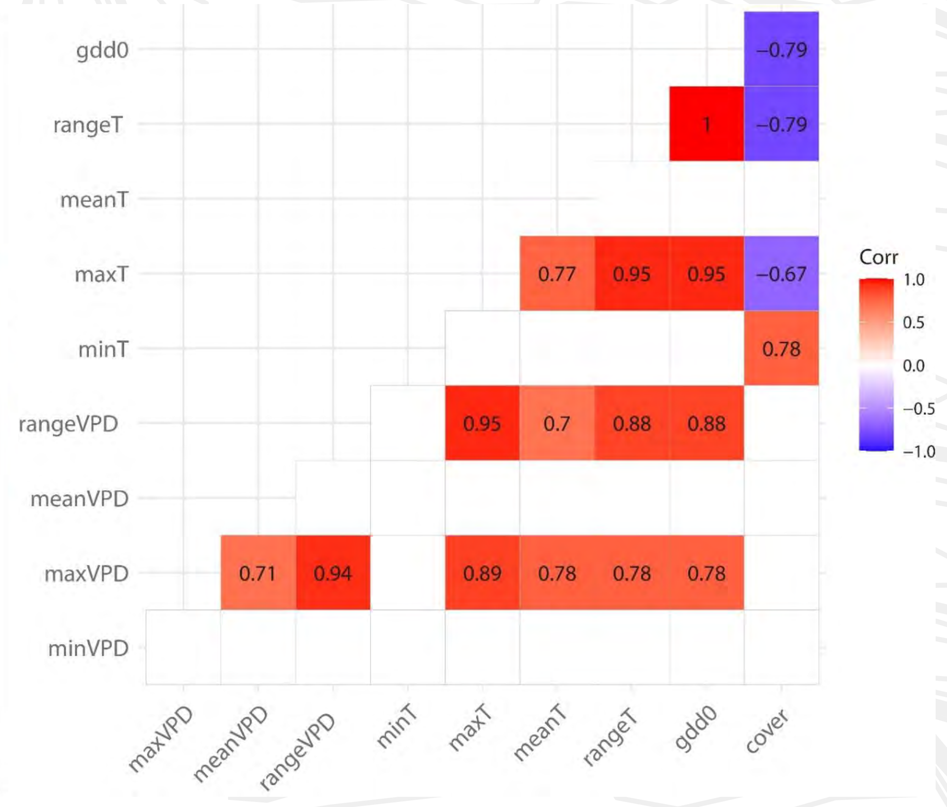


Fig. 2. Spearman correlation matrix for microclimate variables and canopy cover for Haller's Apple Moss sites (for unoccupied habitat sensors). Only significant values displayed (α = 0.05).

Slopes of OLS regression between the region and sensors locations show that maxVPD was buffered from the region in the subcanopy, unoccupied habitat, and for subpopulations (**Fig. 3**). There were pronounced differences in microclimate among sensor locations (**Table 1**). VPD variables often differed among all sensor locations; temperature variables did not differ between unoccupied habitat and subpopulations.

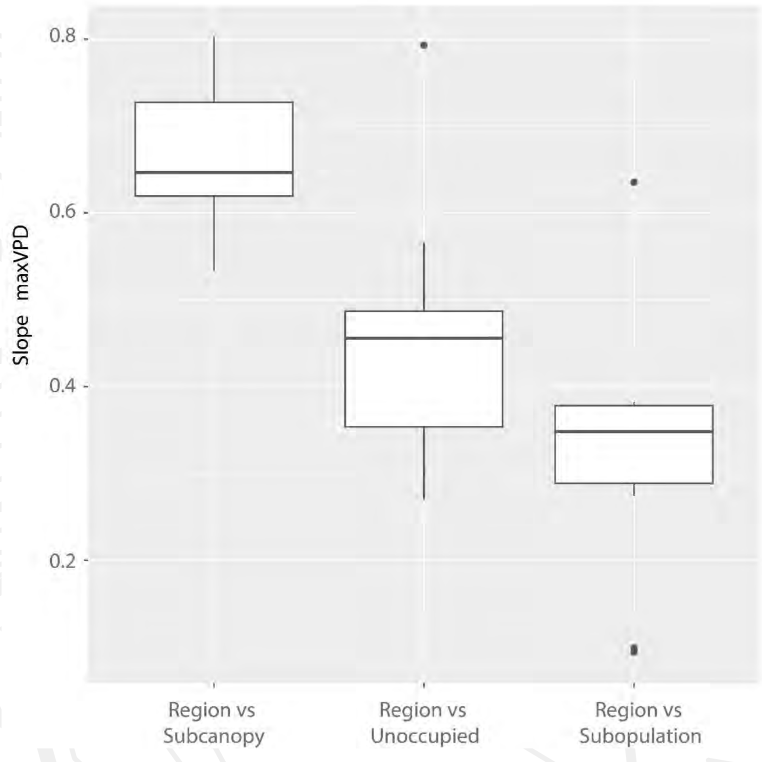


Fig. 3. Boxplots of OLS regression slopes for maxVPD calculated between a) region and subcanopy, b) region and unoccupied habitat, and c) region and subpopulation.

			Sensor location		
		Region	Subcanopy	Unoccupied	Subpopulation
			n = 8	n = 10	n = 11
minVPD	Pa	49.0	21.0 a	17.1 a	5.6 b
maxVPD	Pa	1389.0	792.7 a	456.6 b	308.8 c
meanVPD	Pa	548.4	277.2 a	146.8 b	92.2 c
rangeVPD	Pa	1340.0	771.7 a	439.5 b	303.2 c
minT	°C	6.2	6.9 a	7.5 b	7.5 b
maxT	°C	19.4	16.5 a	14.8 b	14.0 b
meanT	°C	12.7	11.4 a	10.8 b	10.5 b
rangeT	°C	13.2	9.6 a	7.3 b	6.5 b
GDD0	°C	679.5	494.9 a	378.4 b	333.1 b

Table 1. Microclimate variables for the region and sensor locations. Different letters for a variable indicate significant differences between sensor locations based on one-way ANOVA using GLM (α = 0.05).

5. Conclusions

Haller's Apple Moss microhabitats have the capacity to strongly moderate some of the effects of regional climate and may potentially serve as microrefugia for the species under extreme climatic events and climate change[5,6]. This may be relevant for the species given that climate change is forecast to bring warmer and potentially drier conditions throughout the species' North American range[7]. However, the capacity for microhabitats to serve as microrefugia will depend on moderation of regional climate, and tolerance of Haller's Apple Moss to moderated conditions over time.

Tree canopies are known to buffer the effects of regional climate in the understory[8,9]. In this study, higher tree cover moderated temperature and humidity for unoccupied habitat sensors. Unoccupied habitat sensors were in close proximity to subpopulation sensors (mean distance = 4.8 m) but they differed in microclimate. Disturbances that impact forest canopy cover may alter understory microclimate for Haller's Apple Moss.

Rock outcrops are frequent in the study area, but suitable microhabitats for Haller's Apple Moss appear to be highly restricted and infrequent. Future research aims to relate Haller's Apple Moss microclimate to biological attributes of colonies, to better understand microhabitat limitations for the species.

6. References

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7. Acknowledgements

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