

Forest Floor Under Deciduous vs Coniferous Understorey

Conlan Wilson

Abstract

This study investigated the insulative properties of moss layers and their effect on microclimate temperatures within deciduous and coniferous understoreys at British Columbia Ecological Reserve #74. Employing small environment data receiving objects (EDROs), temperatures were monitored both above and below the moss layers and compared to ambient sub-canopy temperatures, exterior to the understorey layer, to delineate the thermal buffering capacity of moss and forest understorey. Over two rounds of three consecutive days, each EDRO recorded approximately 731 to 2122 temperature measurements per round, providing detailed temporal profiles of each microclimate. Results indicated significant differences in temperature regulation by moss; below-moss temperatures were consistently more stable compared to more fluctuating temperatures recorded above the moss and in ambient conditions. Deciduous and coniferous sites saw variations between trials without a clear trend for the understorey type's effect on moss insulation. The study confirmed significant differences across the vertical stratifications and concluded that moss layers significantly moderate ground temperatures, enhancing stability against external temperature fluctuations. However, the results of this study cannot suggest that understorey type influences the magnitude of ground temperature insulation by moss.

Introduction

Understanding the thermal dynamics within forest ecosystems is critical for elucidating various understorey components' roles in influencing microclimatic conditions. Mosses, as significant components of the forest floor, are known to affect local temperature cycles through their insulative properties (Dyrness, 1982; Turetsky et al., 2012; Chen et al., 2019; Park et al., 2021). Previous research has demonstrated that moss layers can moderate soil temperatures, protecting the ground from extreme thermal fluctuations and potentially influencing soil biological processes and plant growth (Turetsky, 2003; Chen et al., 2019). The insulative capacity of moss is believed to vary between different forest types due to variations in canopy cover, which affects solar radiation penetration and local humidity levels (Hart and Chen, 2006; O'Donnelle et al., 2009). Moreover, deciduous and coniferous forests exhibit distinct structural characteristics that may differentially impact the underlying moss layers' temperature buffering capacity (Van Cleve and Viereck 1981; Hart and Chen 2006; Davis et al., 2019).

This study explores how the presence of moss under different types of forest understorey—deciduous and coniferous—affects temperature stability and insulation above and below the moss layer and relative to ambient conditions. This study aims to quantify the temperature differences facilitated by moss layers in deciduous and coniferous forests and assess the moss's role as a thermal buffer. By integrating temperature measurements from below and above the moss layers under different understorey types and comparing these to ambient air temperatures, this research aims to analyze the thermal properties of moss. This information is crucial for forest management strategies, particularly in climate change, where temperature regulation within forest microclimates can influence broader ecological dynamics (Brookshire et al., 2011; Stinziano and Danielle, 2014).

This investigation is an observational study measuring temperature variations of the forest floor within deciduous and coniferous understoreys. It also examines the stability of these temperatures over time to determine the consistency of moss's insulative effects under varying environmental conditions. Understanding these dynamics is essential for predicting how changes in forest composition—due to factors like deforestation, afforestation, or natural succession—might alter forest floor microclimates and the associated biological responses.

The significance of this research lies in its potential to contribute to the body of knowledge regarding the ecological roles of moss and understorey types in forest ecosystems and to inform conservation efforts aimed at preserving these vital organisms and the functions they serve. By clarifying the conditions under which mosses exert their greatest temperature-modulating effects, this study could help pave the way for leveraging natural understorey components to enhance forest resilience to climatic changes.

Methods

This study was conducted at British Columbia Ecological Reserve #74 (ER) within Metro Vancouver's Pacific Spirit Regional Park. This study compared the above and below temperatures of

bryophyte layers within coniferous and deciduous understorey and the ambient sub-canopy temperature outside the understorey layers. I selected one site for each understorey, with the specification requirement being that each location was at least five square meters of the understorey type of interest that measured around three meters in height.

I created small environment data receiving objects (EDROs; Figure A) to allow for real-time temperature readings in the ER. The EDROs were battery-powered ESP8266s with an AHT20 sensor. I programmed the EDROs to wake up in two-minute intervals, perform a temperature reading, and then send it to a battery-powered ESP32 over the ESP32's private WiFi network, which then saved each reading to a microSD card. This approach was critical as the sensors needed to run autonomously in the ER without an external power source. The wires connecting the AHT20 to the ESP8266 on the EDROs above the bryophyte layers and outside the understorey were about six inches long to distance the main computer from the sensor. The AHT20's wire on the EDROs underneath the bryophyte layers was about 18 inches long,

Figure A: Environment Data Receiving Object (EDRO)

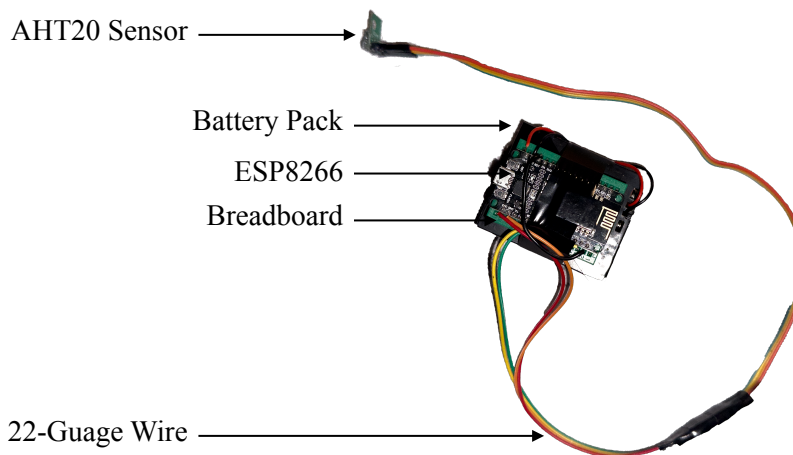


Figure A — An EDRO made of an ESP8266 on a breadboard (green) glued to a battery pack (black), an AHT20 sensor, and fixed 22-gauge wires.

making inserting the sensor underneath the moss layers easier and allowing the sensors to be distanced from the incision opening in the moss layer.

The setup ran concurrently at both sites for three consecutive days, capturing approximately 70 hours of continuous data. An EDRO was placed below the bryophyte layer, above the bryophyte layer and outside the understorey layer (approximately three meters above ground level within the five square meters

area). A general outline of the study setup is shown in Figure B. Each EDRO recorded 731 to 2122 temperature measurements per site per trial, yielding high temporal resolution data. The process was

Figure B: Field Setup

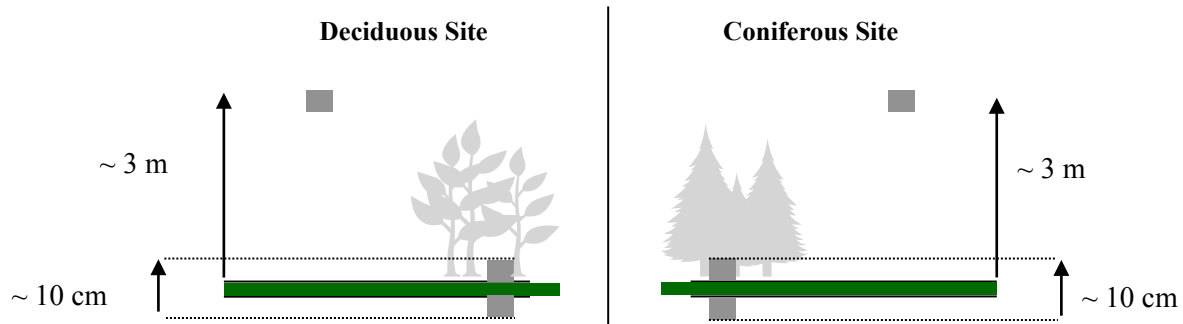


Figure B — A visual of the study's setup in the ER. The grey boxes refer to the EDROs. The moss was approximately 10 cm thick. Figure is not to scale.

repeated once in a second trial, keeping the EDROs in the same place.

Following the trials, all EDROs were placed adjacent to one another in a temperature-controlled area to assess the precision and ensure sensor consistency. This calibration trial determined any sensor variance, which was accounted for in the results. The manufacturer-reported error margin for the AHT20s was $\pm 0.3^{\circ}\text{C}$.

Results

Figure 1 depicts the temperature trends over time from Trial 1 in the deciduous environment, showing temperature data from three different locations: directly below the bryophyte layer, directly above it, and in the ambient environment outside the understorey. The graph features three temperature curves: the curve representing the ambient temperature is generally the lowest, often remaining below 4°C , while the curve for temperatures above the moss fluctuates more, generally staying between 2°C and 6°C . The below-moss temperature curve closely mirrors the above-moss curve but with slightly less variation, mainly ranging between 3°C and 6°C . Notably, there is an 8.5-hour period starting around the 11-hour mark without below-moss data due to a power failure in one of the EDROs.

Figure 2 displays the temperature trends over 67.3 hours from Trial 1 in the coniferous environment. It monitors temperatures at different vertical positions: directly below the bryophyte layer, directly above it,

and in the ambient atmosphere outside the understorey. The curve for temperatures below the moss remains consistently higher throughout the period, mostly between 4°C and 7°C. The above-moss temperature curve is moderately variable, with temperatures typically ranging between 2°C and 6°C. The ambient temperature curve exhibits the most variability and generally trends lower than the above-moss temperatures, often staying below 4°C but occasionally peaking at similar values.

Figure 3 presents the temperature trends over 70.66 hours during Trial 2 in the deciduous environment. It shows measurements taken at three vertical levels: below the bryophyte layer, above it, and in the ambient environment. The temperature below the moss is consistently the highest, predominantly maintaining values between 10°C and 12°C, before experiencing a sharp drop near the 25-hour mark, stabilizing around 8°C and then gradually declining to about 6°C by the end of the trial. The temperatures above the moss exhibit more fluctuations, generally ranging from 6°C to 10°C, closely following the trends of the ambient temperatures but consistently about 1°C to 1.5°C lower. The ambient temperatures are the most variable and overall the lowest, typically oscillating between 4°C and 8°C, showing a similar sharp decline around the 25-hour mark.

Figure 4 shows the temperature-time plot over 55.1 hours from Trial 2 in the coniferous environment, capturing temperatures at three distinct levels: below the bryophyte layer, above it, and in the ambient environment. This graph demonstrates notable temperature trends. The temperatures recorded below the moss layer consistently show the highest readings, starting around 12°C and gradually decreasing, stabilizing just above 10°C. This temperature line remains relatively steady throughout the trial. The temperatures above the moss are lower, with more fluctuation, generally oscillating between 6°C and 8°C and exhibiting a steady decline, with the latter half of the period stabilizing around 6°C. The ambient temperatures exhibit the most variability and are the lowest among the three, typically ranging from 4°C to 7°C, with multiple fluctuations observed throughout the trial period.

Figure 1: Trial 1 Deciduous Temperature

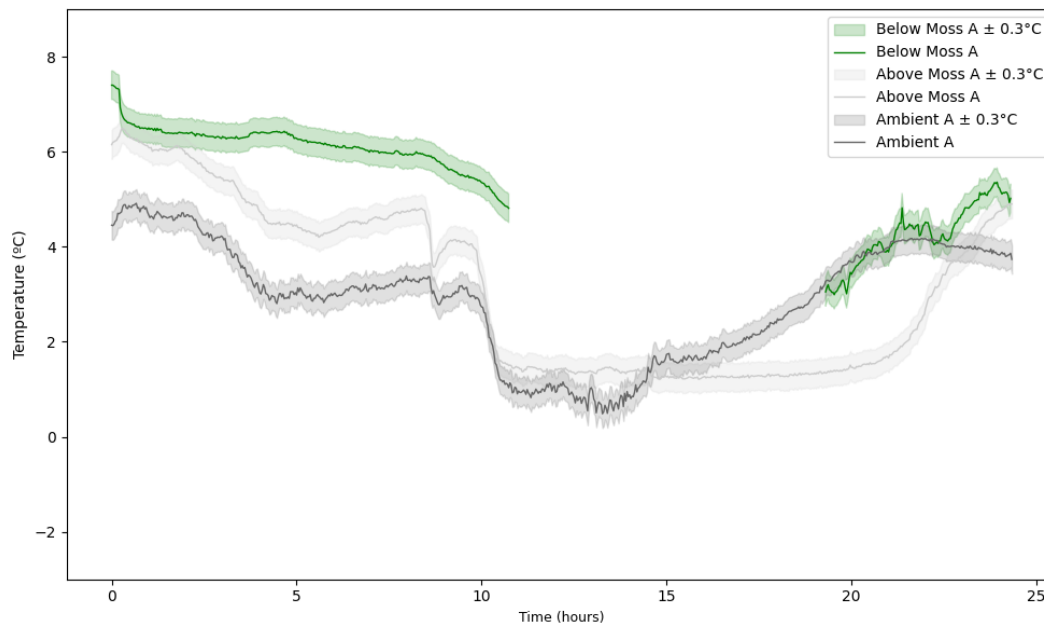


Figure 1 — A temperature-time plot for each EDRO: below the bryophyte layer, above the bryophyte layer, and outside the understorey. Each temperature line has an uncertainty bar of $\pm 0.3^{\circ}\text{C}$. This trial contains 731 temperature readings taken every two minutes over 24.3 hours.

Figure 2: Trial 1 Coniferous Temperatures

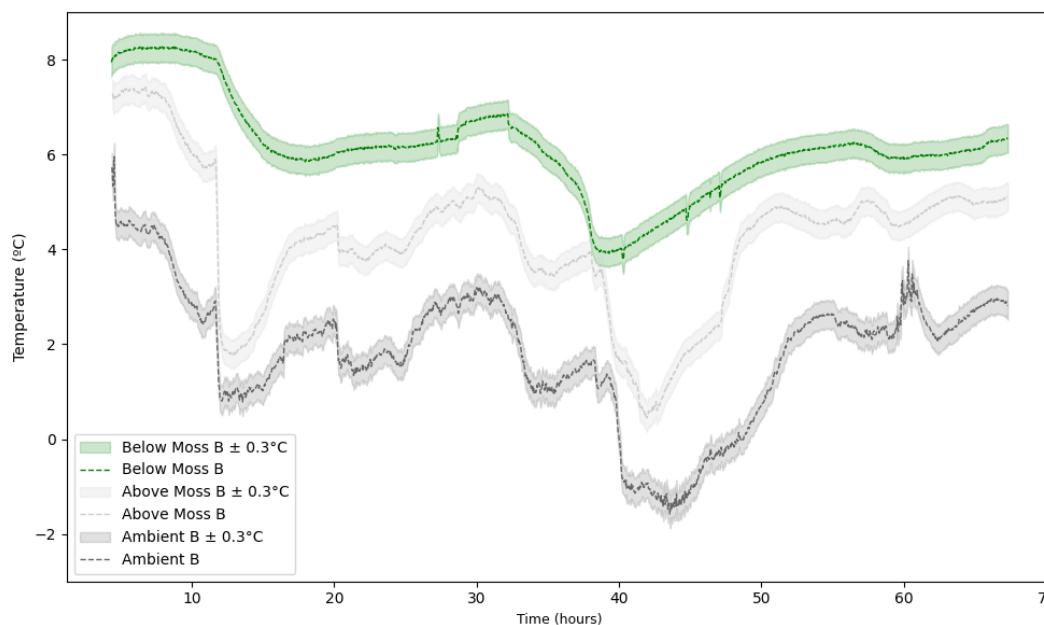


Figure 2 — A temperature-time plot for each EDRO: below the bryophyte layer, above the bryophyte layer, and outside the understorey. Each temperature line has an uncertainty bar of $\pm 0.3^{\circ}\text{C}$. This trial contains 2021 temperature readings taken every two minutes over 67.3 hours.

Figure 3: Trial 2 Deciduous Temperatures

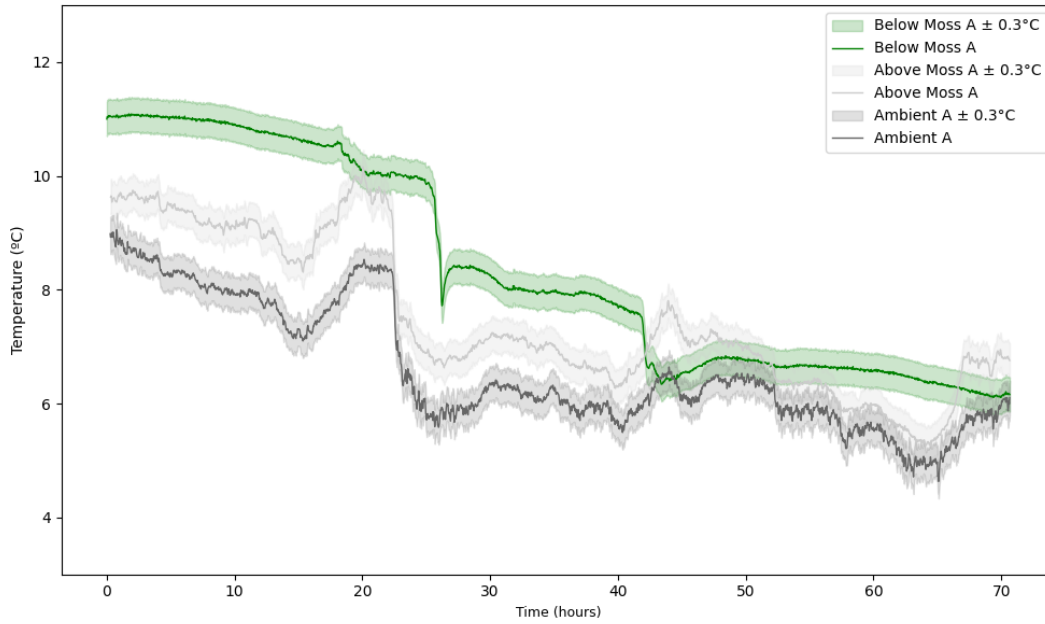


Figure 3 — A temperature-time plot for each EDRO: below the bryophyte layer, above the bryophyte layer, and outside the understorey. Each temperature line has an uncertainty bar of $\pm 0.3^{\circ}\text{C}$. This trial contains 2122 temperature readings taken every two minutes over 70.66 hours.

Figure 4: Trial 2 Coniferous Temperatures

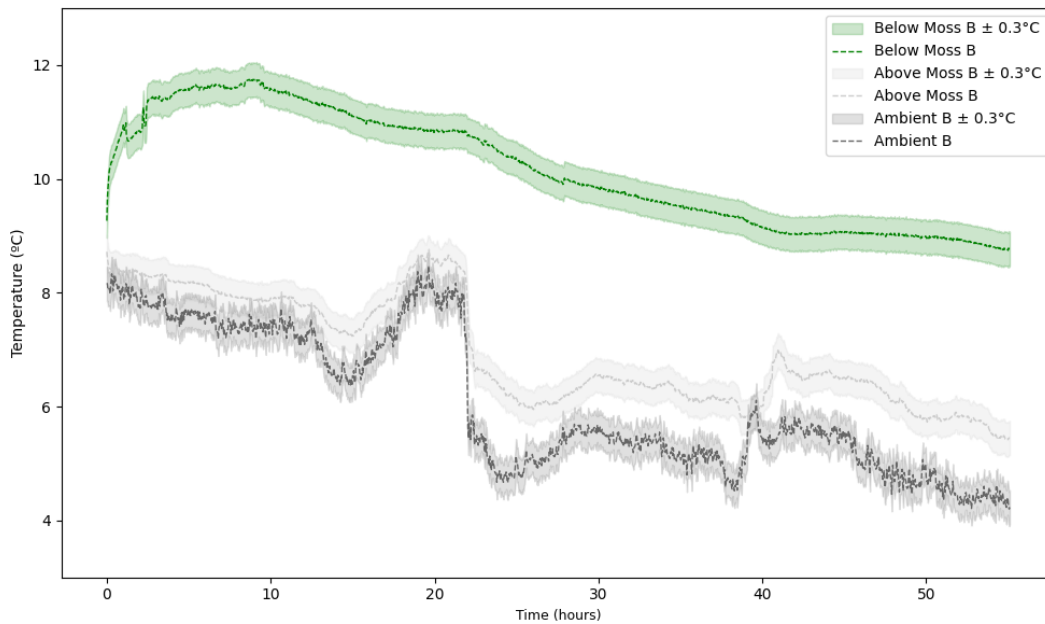


Figure 4 — A temperature-time plot for each EDRO: below the bryophyte layer, above the bryophyte layer, and outside the understorey. Each temperature line has an uncertainty bar of $\pm 0.3^{\circ}\text{C}$. This trial contains 1655 temperature readings taken every two minutes over 55.1 hours.

Figure 5: Below - Above

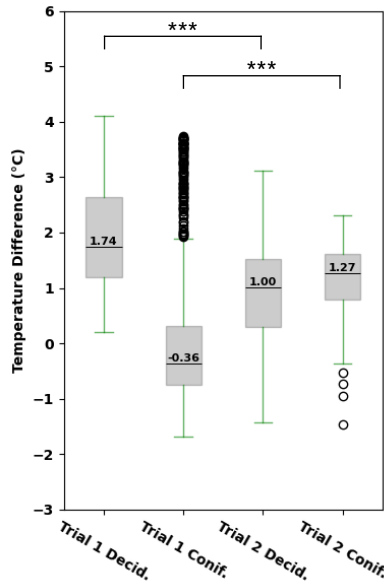


Figure 6: Below - Ambient

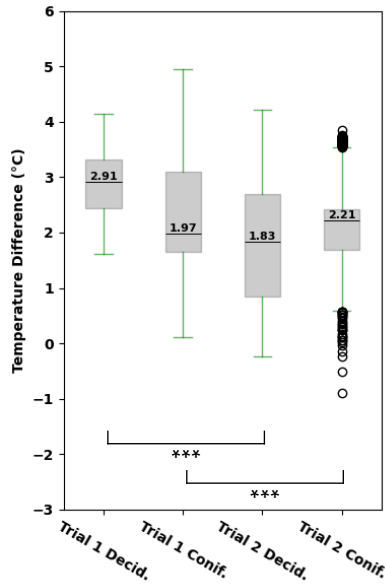


Figure 7: Above - Ambient

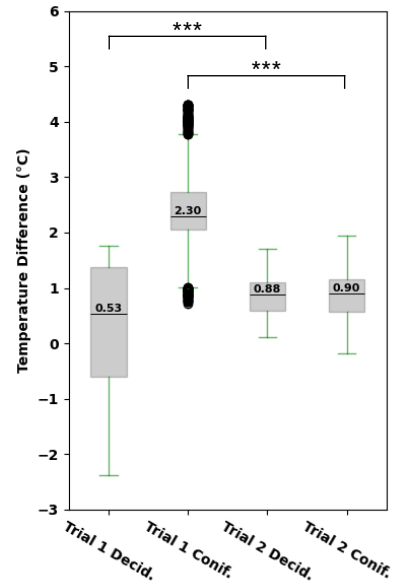


Figure 5 — A box plot of the below moss temperature minus the same-time above moss temperature for each trial site. The deciduous site had medians of 1.74°C and 1.00°C for trials one and two, respectively. The coniferous site had medians of -0.36°C and 1.27°C for trials one and two, respectively. Statistically significant differences ($p < 0.001$) between Trial 1 Deciduous and Trial 1 Coniferous, and Trial 2 Deciduous and Trial 2 Coniferous, are indicated by '***' above the respective comparisons.

Figure 6 — A box plot of the below moss temperature minus the same-time ambient temperature for each trial site. The deciduous site had medians of 2.91°C and 1.83°C for trials one and two, respectively. The coniferous site had medians of 1.97°C and 2.21°C for trials one and two, respectively. Statistically significant differences ($p < 0.001$) between Trial 1 Deciduous and Trial 1 Coniferous, and Trial 2 Deciduous and Trial 2 Coniferous, are indicated by '***' below the respective comparisons.

Figure 7 — A box plot of the above moss temperature minus the same-time ambient temperature for each trial site. The deciduous site had medians of 0.53°C and 0.88°C for trials one and two, respectively. The coniferous site had medians of 2.30°C and 0.90°C for trials one and two, respectively. Statistically significant differences ($p < 0.001$) between Trial 1 Deciduous and Trial 1 Coniferous, and Trial 2 Deciduous and Trial 2 Coniferous, are indicated by '***' above the respective comparisons.

Discussion

The results from the study demonstrate significant microclimatic differences between the temperatures below and above the moss layer and compared to ambient conditions in deciduous and coniferous environments. Figure 5 shows three of the four sites had a significant temperature difference of 1.00°C to 1.74°C between below and above the moss. Figure 6 shows that all sites had a significant temperature difference of 1.83°C to 2.91°C between below the moss and outside the understory environment. This suggests that both moss and the understory act as an insulative layer to the forest floor, which appears to moderate ground temperatures relative to air temperatures above and the ambient conditions, consistent with the insulation properties reported in prior studies (Dyrness, 1982; Hart and Chen, 2006; Blok et al., 2011; Soudzilovskaia et al., 2013; Park et al., 2018). Although the results suggest a degree of magnitude for the moss' insulativeness, the direction remains unknown (i.e., if the moss is strictly warming as it did in this study or if it could provide cooling insulation during different seasons). Looking at Figures 1 through 4, all sites had the below moss layer being notably more stable compared to the more variant temperatures of the above moss and ambient areas. This suggests that the moss layer not only acts as an insulator but also as a buffer. However, the understory appears to provide only insulative properties; the understory does not act as a buffer, as the above moss temperatures follow the ambient temperatures with a similar rate of change.

Figures 5 and 6 show that the temperature differences under deciduous understory are greater than those under coniferous in trial one but lesser than those under coniferous in trial two. While the results suggest that moss and understory offer significant insulation to the forest floor, they do not show an overall trend in the difference between the understory type and the insulation of the forest floor. In other words, the results are inconclusive regarding the effect of the type of understory on the forest floor temperature.

This study could have been significantly strengthened by incorporating additional control sites, specifically areas with deciduous and coniferous understory that lack moss coverage and completely bare sites with no understory or moss. Including these controls would allow for a more robust comparison of temperature differences directly attributable to the presence of moss and understory, isolating their individual and combined thermal effects. These control sites are necessary to definitively attribute observed temperature modulations to the moss itself, as other understory elements could also influence

microclimatic conditions. For example, the thermal properties of the forest floor not covered by the understorey could differ significantly from those within the deciduous or coniferous understorey, potentially due to differences in soil moisture retention, exposure to solar radiation, ground topography, and branch litter. Therefore, the absence of these control groups in the study design leaves a gap in understanding the precise role of moss versus other understorey components, potentially confounding the interpretation of how understorey type contributes to microclimate regulation within forested ecosystems. This limitation restricts the conclusive generalization of the results across different forest management and conservation practices.

Further insight into the insulation properties of bryophyte layers under deciduous and coniferous understorey could be achieved by conducting these observations across different seasons. Seasonal variations, such as changes in precipitation, solar angle, and vegetation phenology, could substantially influence moss layers' insulative and buffering capacity. More trials would capture these dynamic conditions, providing a more comprehensive understanding of how moss and understorey interact with environmental factors throughout the year. For instance, the insulating effects of moss might be enhanced during wetter seasons due to increased water retention, while reduced effectiveness might be observed during dry seasons or in freezing conditions when physiological changes occur within the moss structure (Atanasiu, 1971). Additionally, by performing longer trials, it would be possible to see the below moss make a complete oscillation in temperature. As seen in Figures 1, 3, and 4, the temperature below the moss mainly was cooling. Longer trials would allow for periods of warming, which would then show oscillating temperature curves below the moss, as seen in Figure 2. Using these curves, it may be possible to construct a temperature gradient model with a respective heat capacity to quantize the thermal insulative properties of moss and understorey type.

The strength and reliability of these results can also be significantly reinforced by performing multiple trials for each understorey type. Replicating trials could increase the robustness of the study by minimizing the effects of anomalous data and allowing for more precise estimates of average conditions. This approach would help clarify any inconsistencies observed between trials, as noted in the varying temperature differences under deciduous and coniferous understories between trials one and two. By averaging over multiple trials, we could reduce the impact of outliers or unique environmental events that may skew results in a single trial. This could also provide a more solid statistical foundation for comparing

the insulation effects of moss under different types of understorey, thus possibly offering more explicit guidance for forest management practices that aim to leverage natural insulation for climate control or habitat management.

In summary, expanding the scope of the study to include more extended monitoring periods and additional replicates could provide a deeper, more reliable understanding of how bryophyte layers function as insulators under varying environmental and climatic conditions, like forest understorey. Such comprehensive data may become essential for developing effective conservation strategies and managing forest ecosystems in changing global climates.

Conclusion

The results of this study illustrate that moss layers enhance thermal stability on the forest floor, demonstrating a marked difference in temperature regulation between the layers below and above the moss, as well as compared to the ambient conditions. Specifically, temperature differences of up to 1.74°C were recorded between the below and above moss layers and up to 2.91°C between the below moss and ambient temperatures. This study confirms that moss acts as both an insulator and a stabilizer of ground temperatures, mitigating the effects of external temperature fluctuations. Although variations were observed between deciduous and coniferous understorey types, these did not follow a consistent trend across trials, suggesting that other environmental or biological factors may influence the insulative properties of moss. The significance of this work lies in its contribution to the understanding of microclimatic regulation by moss layers, potentially informing conservation strategies and forest management practices aimed at leveraging natural understorey components to enhance ecosystem resilience to climate variability.

Acknowledgements

I acknowledge that the University of British Columbia, Point Grey campus, is located on the traditional, ancestral and unceded territory of the xwməθkwəy̓əm (Musqueam) people. I acknowledge the University of British Columbia for offering *Biology 342: Integrative Biology Laboratory* and allowing me to complete this research as part of the course.

References

1. Atanasiu, L. (1971). Photosynthesis and Respiration of Three Mosses at Winter Low Temperatures. *The Bryologist*, 74(1), 23-27. <https://doi.org/10.2307/3241751>
2. Blok, D., Heijmans, M. M., P, D., Schaepman-strub, G., van Ruijven, J., . . . Berendse, F. (2011). The cooling capacity of mosses: Controls on water and energy fluxes in a Siberian tundra site. *Ecosystems*, 14(7), 1055-1065. <https://doi.org/10.1007/s10021-011-9463-5>
3. Brook, R. T., Kyker-Snowman, T. D. (2008) Forest floor temperature and relative humidity following timber harvesting in southern New England, USA. *Forest Ecology and Management*, 254(1), 65-73. <https://doi.org/10.1016/j.foreco.2007.07.028>
4. Brookshire, J. E., Gerber, S., Webster, J. R., Vose, J. M., & Swank, W. T. (2011). Direct effects of temperature on forest nitrogen cycling revealed through analysis of long-term watershed records. *Global Change Biology*, 17(1), 297-308. <https://doi.org/10.1111/j.1365-2486.2010.02245.x>
5. Burgess-Conforti, J., Moore Jr, P. A., Owens, P. R., Miller, D. M., Ashworth, A. J., Hays, P. D., . . . Anderson, K. R. (2019). Are soils beneath coniferous tree stands more acidic than soils beneath deciduous tree stands? *Environmental Science and Pollution Research*, 26(15), 14920-14929. <https://doi.org/10.1007/s11356-019-04883-y>
6. Chen, S., Yang, Z., Liu, X., Sun, J., Xu, C., Xiong, D., . . . Yang, Y. (2019). Moss regulates soil evaporation leading to decoupling of soil and near-surface air temperatures. *Journal of Soils and Sediments*, 19(7), 2903-2912. <https://doi.org/10.1007/s11368-019-02297-4>
7. Davis, K. T., Dobrowski, S. Z., Holden, Z. A., Higuera, P. E., & Abatzoglou, J. T. (2019). Microclimatic buffering in forests of the future: The role of local water balance. *Ecography*, 42(1), 1-11. <https://doi.org/10.1111/ecog.03836>
8. Dyrness, C. T. (1982). Control of Depth to Permafrost and Soil Temperature by Forest Floor in Black Spruce/Feather Moss Communities. *US Department of Agriculture*, Research Note PNW-396.
9. Hart S. A., Chen H. Y. (2006). Understory vegetation dynamics of North American boreal forests.

Crit. Rev. Plant Sci., 25, 381-397.

10. Jean, M., Alexander, H., Mack, M., Johnstone, J. (2017). Patterns of bryophyte succession in a 160 year chronosequence in deciduous and coniferous forests of boreal Alaska. *Canadian Journal of Forest Research*, 47(8), 1021-1032. <http://dx.doi.org/10.1139/cjfr-2017-0013>
11. Manríquez, M. D. R., Ardiles, V., Promis, Á., Herrera, A. H., Soler, R., Lencinas, M. V., & Martínez Pastur, G. (2020). Forest canopy-cover composition and landscape influence on bryophyte communities in Nothofagus forests of southern Patagonia. *PloS one*, 15(11), e0232922. <https://doi.org/10.1371/journal.pone.0232922>
12. Mestre, L., Toro-manríquez, M., Soler, R., Huertas-herrera, A., Martínez-pastur, G., & Lencinas, M. V. (2017). The influence of canopy-layer composition on understory plant diversity in southern temperate forests. *Forest Ecosystems*, 4(1), 1-13. <https://doi.org/10.1186/s40663-017-0093-z>
13. O'Donnell, J., Romanovsky, V. E., Harden, J. W., McGuire, D. (2009). The Effect of Moisture Content on the Thermal Conductivity of Moss and Organic Soil Horizons From Black Spruce Ecosystems in Interior Alaska. *Soil Science*, 174(12), 646-651.
14. Park, H., Launiainen, S., Konstantinov, P. Y ., Iijima, Y ., & Fedorov, A. N. (2018). Modelling the Effect of Moss Cover on Soil Temperature and Carbon Fluxes at a Tundra Site in Northeastern Siberia. *Journal of Geophysical Research: Biogeosciences*, 123(9), 3028–3044. <https://doi.org/10.1029/2018JG004491>
15. Pfeifer, M., Boyle, M. J. W., Dunning, S., & Olivier, P. I. (2019). Forest floor temperature and greenness link significantly to canopy attributes in South Africa's fragmented coastal forests. *PeerJ*, 7, e6190. <https://doi.org/10.7717/peerj.6190>
16. Robinson S. I., McLaughlin Ó. B., Marteinsdóttir B., O'Gorman E. J (2018). Soil temperature effects on the structure and diversity of plant and invertebrate communities in a natural warming experiment. *Journal of Animal Ecology*, 87(3), 634–646. <https://doi.org/10.1111/1365-2656.12798>

17. Rollinson, C. R., Alexander, M. R., Dye, A. W., Moore, D. J. P., Pederson, N., & Trouet, V. (2021). Climate sensitivity of understory trees differs from overstory trees in temperate mesic forests. *Ecology*, *102*(3), 1–11. <https://www.jstor.org/stable/26998117>
18. Soudzilovskaia, N. A., van Bodegom, P. M., & Cornelissen, J. H. C. (2013). Dominant bryophyte control over high-latitude soil temperature fluctuations predicted by heat transfer traits, field moisture regime and laws of thermal insulation. *Functional Ecology*, *27*(6), 1442–1454. <http://www.jstor.org/stable/24034013>
19. Stinziano, J. R. and Danielle, A. W. (2014). Combined effects of rising [CO₂] and temperature on boreal forests: growth, physiology and limitations. *Botany*, *92*(6): 425-436. <https://doi.org/10.1139/cjb-2013-0314>
20. Turetsky, M. R. (2003). The role of bryophytes in carbon and nitrogen cycling. *The Bryologist*, *106*(3), 395-409.
21. Turetsky M.R., Mack M.C., Hollingsworth T.N., and Harden J.W. (2010). The role of mosses in ecosystem succession and function in Alaska's boreal forest. *Canadian Journal of Forest Research*, *40*(7), 1237-1264.
22. Turetsky M.R., Bond-Lamberty B., Euskirchen E., Talbot J., Frohking S., McGuire A.D., and Tuittila E.S. (2012). The resilience and functional role of moss in boreal and arctic ecosystems. *New Phytologist*, *196*, 49-67.
23. Van Cleve K., Viereck L.A. (1981). Forest succession in relation to nutrient cycling in the boreal forest of Alaska. *Forest Succession*, 184–211.
24. Wilson, E. F. (2006). The effect of overstory canopy density alterations on air temperature in a managed redwood forest. *California State Polytechnic University, Humboldt*. <http://hdl.handle.net/2148/91>
25. Wu, H., Hu, B., Yan, J., Cheng, X., Yi, P., Kang, F., Han, H. (2023). Mixed plantation regulates forest

floor water retention and temperature sensitivity in restored ecosystems on the Loess Plateau, China. *CATENA*, 222. <https://doi.org/10.1016/j.catena.2022.106838>