Biogeosciences

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Discussions

Interactive comment on "The decline of alpine lichen heaths generates atmospheric heating but subsurface cooling during the growing season" *by* Peter Aartsma et al.

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We thank Reviewer 1 for his/her time to review our manuscript and for his/her valuable comments. Below are our answers on his/her comments.

Reviewer comment: This paper investigates the effect of lichen cover on alpine tundra microclimates, relative to increased shrub cover growth. The authors use two years worth of vegetation and microclimate data collected in Alpine Norway and find that a decline in lichens and increase in shrub cover lead to an overall atmospheric heating effect. I think this is a really well framed research gap highlighting an understudied and potentially very important research gap. While the data only come from one site, I think

the topic is in the scope of Biogeosciences, as it has potential tundra-wide implications. I think the paper is overall clearly written, with a thorough methodology, and interesting discussion. However, I propose that this paper be reconsidered after major revisions because I feel like more work could be done to frame the research in the context of ecosystem-wide change, and I think more work could be done to frame hypotheses from the beginning of the paper.

Author response: We thank the Reviewer for his/her positive words concerning the importance of our study and the writing style of the paper. Below we reply in detail to his/her comments concerning the framing of the hypotheses and the framing of our research in the context of ecosystem-wide change.

Reviewer comment: The introduction and literature review is concise and persuasive, but I feel as though you could state clear hypotheses at the end of this section to better frame the rest of the paper. You have nice comprehensive microclimate measurements, and your methods section is replicable and thorough. I think your results section works well although I have provided some comments on the figures. Finally, I'd like to see more discussion of the implications of these findings for other alpine and Arctic tundra sites - do you expect to see similar trends across the biome? What significance do you think this has for the ecosystem as a whole? Do you expect to see similar trends in the Arctic tundra too, or just Alpine sites - and what is your justification for this? Finally, how much do you think shrub species matter in explaining the variation in your data? Are all tundra shrubs out-competing all lichens? I think this could be an interesting line of enquiry. I'm looking forward to reading this paper again!

Author response: We thank the Reviewer for his/her positive feedback concerning the introduction, methods and results section. In the new version of the manuscript, we will list the hypotheses at the end of the introduction in order to frame the rest of the paper. We will also discuss more extensively the more general implications of our findings for other alpine and Arctic areas. We see that this is necessary since our measurements were conducted on one field site. To elaborate on the question if we

expect similar trends across the biome, we will include more studies that have been measuring microclimatic conditions below lichens and shrubs in alpine and Arctic areas before (e.g. Grünberg et al., 2020; Loranty et al., 2018; Mikola et al., 2018). Moreover, we will use articles that studied the implications of shrubification on alpine and Arctic areas (e.g. Chagnon & Boudreau, 2019; Frost et al, 2018; Lafleur & Humphreys 2018), to discuss if we expect different results between different tundra shrubs species and shrub characteristics (e.g. shrub height, shrub density) concerning the variation in microclimate between lichens and shrubs. We agree that this additional discussion is of relevance for our manuscript.

Reviewer comment: - generally, you should capitalise 'Arctic'

Author response: We will capitalize "Arctic" in the new version.

Reviewer comment: -21: "we hypothesise" - reword. The placement of this phrase in the abstract makes it seem like a hypothesis you set at the beginning relating to this project as opposed to a theory you generated based on your results

Author response: We see the point that the Reviewer makes and will replace "hypothesize" with "predict".

Reviewer comment: - 33: "this region" - I understand from context, but you could make it clearer which region you mean in this sentence (i.e. are you still talking about the Western Canadian Arctic, or Alpine Norway again?)

Author response: We will make this clearer.

Reviewer comment: - 36: not clear from this sentence if lichen is declining purely because of competition with shrubs, or if they aren't coping physiologically with a rapidly warming temperature

Author response: We will elaborate more on this in the new version.

Reviewer comment: - 61: I'd call it "macroclimate" instead of "large climate"

Author response: We will replace "large-scale climate" with "macroclimate".

Reviewer comment: - Figure 2:: could you add the letter labels to the photography too? Its currently quite hard to envision.

Author response: We will add the letter labels in the photography of Figure 2.

Reviewer comment: - 161: be explicit here, what is the interaction and why did you include it? We get the interaction later on in the tables but I feel you could spell it out here.

Author response: We will elaborate more on the interaction term in the new version of the manuscript and explain why we included it.

Reviewer comment: - Tab 2: maybe you should also add a column saying how much variation in % is explained by your random effects? Also you should add the slope/estimate and error in this table, as the F and P values are not very informative on their own.

Author response: We will add the slope and error in Table 2 and will add a column saying the marginal and conditional r-squared for each model. The marginal r-squared is the variation explained by the fixed effects and the conditional r-squared is the variation explained by the entire model. Since Table 2 will get rather large when we add this information for the daily, daytime and nighttime analysis, we will report only the table with the analysis of the daily averages/totals in the main text and will place the table with the analysis of the daytime and nighttime averages/totals in the Appendix.

Reviewer comment: - Figure 4: a nice clear figure. Move the (d) label up a bit, it looks a bit cluttered at the moment.

Author response: We will move the (d) label a bit up.

Reviewer comment: - Figure 5: looks great but I'd recommend changing the colours from red to blue to something less indicitive of temperature. Currently it suggests

lichens = hot, shrubs = cold.

Author response: We will change the colors in all the figures from red and blue into light-green (for lichens) and dark-green (for shrubs). See Figure 1 below for an example.

Reviewer comment: - Figure 8: useful site information, but maybe move to supplementary materials? You have a lot of figures and I feel like this one can be moved.

Author response: We will move Figure 8 to the Appendix.

Reviewer comment: - 298: "tundra plots" vs "shrub plots" = this is confusing because tundra can be very shrubby. Maybe rename these descriptors to make this more explicit?

Author response: We see the point made by the Reviewer and will change the term "tundra plots" into "open tundra plots". The plots in line 298 refers to the study of Myers-Smith and Hik (2013), who refer to them as "open plots" in their paper.

References used by author:

Chagnon, C., & Boudreau, S. (2019). Shrub canopy induces a decline in lichen abundance and diversity in Nunavik (Québec, Canada). Arctic, Antarctic, and Alpine Research, 51(1), 521-532.

Frost, G. V., Epstein, H. E., Walker, D. A., Matyshak, G., & Ermokhina, K. (2018). Seasonal and long-term changes to active-layer temperatures after tall shrubland expansion and succession in Arctic tundra. Ecosystems, 21(3), 507-520.

Grünberg, I., Wilcox, E. J., Zwieback, S., Marsh, P., & Boike, J. (2020). Linking tundra vegetation, snow, soil temperature, and permafrost. Biogeosciences, 17(16), 4261-4279.

Lafleur, P. M., & Humphreys, E. R. (2018). Tundra shrub effects on growing season energy and carbon dioxide exchange. Environmental Research Letters, 13(5), 055001.

Loranty, M.M., Berner, L.T., Taber, E.D., Kropp, H., Natali, S.M., Alexander, H.D., Davydov, S.P. and Zimov, N.S., 2018. Understory vegetation mediates permafrost active layer dynamics and carbon dioxide fluxes in open-canopy larch forests of northeastern Siberia. Plos one, 13(3), p.e0194014.

Mikola, J., Virtanen, T., Linkosalmi, M., Vähä, E., Nyman, J., Postagonova, O., Räsänen, A., Kotze, J., Laurila, T., & Juutinen, S. (2018). Spatial variation and linkages of soil and vegetation in the Siberian Arctic tundra–coupling field observations with remote sensing data. Biogeosciences, 15(9).
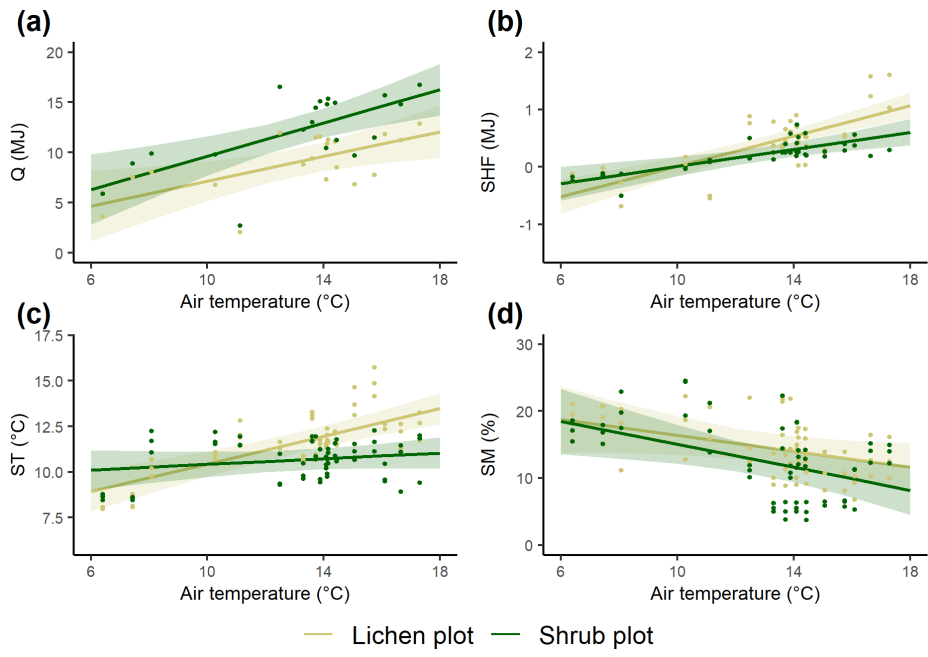
Fig. 1. Example of Figure 5 with the new colors.