Title: **Fungal Response to Multiple Global Change Stressors: Evidence from Long-Term Manipulations and Environmental Gradients**

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Project Abstract:
Global change is affecting terrestrial ecosystems in multiple ways. In mountain ecosystems, direct effects (e.g., raised soil temperatures) and indirect effects (e.g., early snowmelt, decrease in snowpack) of warming are co-occurring. Our ability to forecast belowground responses to these complex global change drivers has been hindered by a lack of long-term studies. Yet, these belowground studies are vital as soil fungi are key decomposers in terrestrial ecosystems, potentially flipping soils from carbon sinks to carbon sources. Here we examined soil fungal responses (composition and abundance) to a 29-year-long warming experiment and a 4-year-long early snowmelt manipulation at the Rocky Mountain Biological Laboratory in Gothic, Colorado in 2019-2021. These data were paired with those collected the same year from nearby environmental gradients in temperature (e.g., elevation) and snowmelt date (e.g., at different slopes and aspects). These approaches are complementary. Environmental gradients capture long-term ecological and evolutionary variation but can be confounded by many covarying abiotic and biotic factors. Long-term experiments allow us to understand the role of a specific global change driver but may not occur over long enough time periods to capture both ecological and evolutionary responses.

Soil fungal communities varied substantially in response to abiotic environmental gradients. Up to 8% of the variation in fungal composition was explained by elevation (a long-term proxy for temperature) and 15% of variation in fungal composition was explained by aspect (a long-term proxy for snowmelt date). Snowmelt date in the collection year explained an additional 10% of variation in fungal composition. Experimental treatments affected fungal communities less. Experimental early snowmelt explained 6% of the variation in fungal communities whereas warming only explained 4% of the variation in fungal communities. Fungal abundance followed similar trends with hyphal lengths varying the most by elevation and aspect, and the least in experimental manipulations. Overall, our results suggest that fungi are more sensitive to historical and contemporary snowmelt date (which varies by 56 days since 1975) than the direct effects of warming per se. Because fungal response to snowmelt is strong, and snowpack and melt dates are highly variable, future ecosystem models may be improved by including fungal functions across the transition in snow cover. Future research in our group is focused on comparing plant, fungal, and biogeochemical phenology in response to snowmelt date.