Effects of warming, dominant species removal, and accelerated snowmelt on aboveground plant traits in the Colorado Rocky Mountains

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Abstract

Noticeable changes such as the alteration of ecosystem productivity, the influence of species interactions with one another and its environment, and the transformation of habitats are all linked to climate change. Although plant functions might be a useful tool in understanding plant communities and ecosystems, it's time-consuming and expensive. Instead, we can observe aboveground plant traits, which are virtual indicators of the health conditions of plant communities. Measuring how plant traits respond to global change drivers is a useful way to predict plant and ecosystem functioning in future climates. For example, Plant height is a proxy for light capture, and leaf mass per area (LMA) is a great indicator of leaf photosynthetic capacity. We aimed to discover the effects of warming, dominant species removal and accelerated snowmelt on aboveground plant traits in the Colorado Rocky Mountains. This project took place in a montane meadow in Almont, Colorado where the warming and dominant species removal experiment exists, and in Gothic, Colorado where the accelerated snowmelt manipulation is located. At Almont, we saw that the response of plant height to the experimental treatments depended on the species and a combination of treatments. In total eight out of 15 plant species responded to the treatments in some way. There was also no significant response of leaf mass per area (LMA) to the experimental treatments, instead, LMA depended only on the plant species. There was a similar response of chlorophyll content (SPAD) at Almont, Colorado, where the response depended on the species and the treatments. Contrary to what we found in Almont, in Gothic, Colorado there was no significant response of plant chlorophyll content (SPAD) to the experimental treatments, instead, SPAD depended only on the plant species. These results indicate the complexity of plant trait responses and how dynamic they can be in different locations under numerous climate conditions. Understanding these responses is important because they can help us understand how plant communities in montane meadows might change under future climate scenarios.

Introduction

Climate change is a growing issue, leading species to decline and influencing species interactions globally (Durney et al., 2022). Various ways in which climate change can affect ecosystems are through changes in precipitation, temperature, and snowmelt timing or phenology, all of which can influence species ranges and abundance (Durney et al., 2022). Montane meadow communities' species composition and vegetation condition are closely linked to environmental conditions and are especially sensitive to climate change (Debinski et al., 2000). For example, as mid-summer temperatures have warmed, it has been found that montane meadow ecosystems in the southern Rocky Mountains of the United States exhibit a trend toward a bimodal distribution of flower abundance, characterized by a mid-season reduction in

total flower number, instead of a broad, unimodal flowering peak lasting most of the summer season (Aldridge et al., 2011). Climate change is the leading cause of global loss of native and non-native plant species in montane meadows by facilitating tree and shrub encroachment at high elevations. This occurrence happens due to increased woody plant cover in alpine and subalpine ecosystems, which alters surface reflectance (Jackson et al., 2016). This leads to further warming, impacts disturbance regimes, and facilitates shifts in wildlife distributions such as increasing competition and predation from low-elevation generalist and invasive species (Jackson et al., 2016). Changes in the timing of events such as snowmelt can affect species phenology. This may have detrimental effects on plant communities and those species with which they interact (Durney et al., 2022), such as pollinators. These various events could affect the way ecosystems function in the future.

One pathway that can be used to observe or measure plant trait responses to environmental conditions is plant eco-physiological traits. These include plant reproduction, growth, development, and photosynthesis which are all key plant functions that impact ecosystems. But plant eco-physiological traits can be time-consuming to measure and thus often absent from trait databases, so they are rarely used to predict changes in plant communities' composition (Visakorpi et al., 2022). Instead, most studies predicting climate change responses in plant communities rely on morphological traits (e.g. leaf mass per area, height), which are assumed to indirectly describe species physiology and resource acquisition (Visakorpi et al., 2022). For example, leaf mass per unit area (LMA) has been shown to be a good indicator of a leaf's photosynthetic capacity, while plant height is indicative of light capture. There are adapted traits that are associated with high LMA, this being thick leaf blades and small and thick-walled cells, that plants use to sustain continuous leaf function in hard and dry conditions (Wright et al., 2004). As taller plants shade shorter plants, competition favors additional expenditure on stems, opening an evolutionary arms race for light (Falster & Westoby, 2005). Therefore, measuring how plant traits respond to global change drivers is a useful way to predict plant and ecosystem functioning in future climates.

With harsh environmental conditions, it is most likely for certain plant species to succeed if they have the right survival strategies and above-ground traits compared to those that don’t or fail to adapt. For example, plant species that have deeper roots have access to groundwater when there is a water scarcity issue due to an increase in temperatures. In comparison, plants that have shallow roots are less likely to thrive as they are unable to access deeper groundwater. So it is important to research how dominant plant species might affect their neighborhood vegetation communities with increasing temperatures. Studies have already shown that when the dominant plant species biomass was removed, there was an increase in LMA and specific root length in plant communities (Britton et al., 2021). LMA was also an increased trait within warmed plots compared to the species removal where LMA was seen to decrease (Britton et al., 2021). A long-term experimental warming project, which took place in the subarctic tundra, found that plant species were taller, and had wider and longer leaves, compared to those in the control plots (Baruah et al., 2017). Although there might be consistent results between these two

environmentally manipulated changes, both warming and dominant species removal experiments have only been conducted in isolation. However, interactive effects are likely to be important.

Similarly, studies have shown that early snowmelt manipulation is a factor that changes plant trait variation. On Mt. Washington, New Hampshire, there was an experiment that looked at plant traits across a snowmelt gradient at alpine snowbanks sites. They selected five abundant species: *Carex bigelowii*, *Chamaepericlymenum canadense*, *Clintonia borealis*, *Coptis trifolia* , and *Maianthemum canadense*, and it was shown that LMA increased with an earlier snowmelt date. As a result, plant height, and leaf area increased for four species, while the leaf dry matter content (LDMC) decreased (Berend et al., 2022). However, there are relatively few studies relating plant traits to early snowmelt manipulation, and those that have been published have had inconsistent results.

In this study, I aimed to research the difference in traits due to warming, species removal, and early snowmelt, using manipulation experiments in the Rocky Mountains, Colorado. I hypothesized that snow-manipulated plots would have more leaf mass per area (LMA) compared to control plots due to early access to light which implements a longer photosynthesis period. Meanwhile, I expected that the warm plots would have a lower LMA compared to the control plots due to an increase in photosynthetic rate. It also was expected that the dominant species removal plots would have an increase in LMA, height, and leaf thickness compared to the control plots due to the availability of space and nutrients. Overall, I anticipated seeing differing trait responses across species based on the different strategies in response to environmental changes.

Materials and Methods

Study site

This study was conducted from late June to mid-July 2023, in two locations. The first site is located in Almont, Colorado near Jack's Cabin Cutoff (38°38' 59.8956' ' N 100°0' 0" W) where the warming and plant species-dominant removal research is taking place. There are eight blocks containing four 2 x 2 meter squared plots: the warming plot, ambient control, the dominant plant species (*Wyethia amplexicaulis*) removal, and lastly both the warming and dominant species removal treatments (Fig 1.). There was an active ant hill in plot one (warm treatment), as a result, no measurements were collected. In the warming plots, there is a plastic open-top dome surrounding the vegetation. This dome helps trap light, which results in an increased temperature of two degrees Celsius. To protect the plots from any physical damage due to large-bodied animals such as cows, there is an electric fence surrounding the site. On this montane plane, the most abundant species were: *Alopecurus pratensis, Achillea millefolium, Artemisia tridentata, Antennaria rosea, Bromus inermis, Collomia linearis, Elymus elymoides, Eremogone congesta, Erigeron speciosus, Festuca thurberi, Galium septentrionale,*

Helianthella quinquenervis , Penstemon strictus, Poa pratensis, Potentilla congesta, Rosa woodsii, Taraxacum officinale, Wyethia amplexicaulis, Geranium viscosissimum, Iris missouriensis, Lathyrus leucanthus, and *Senecio sp.*

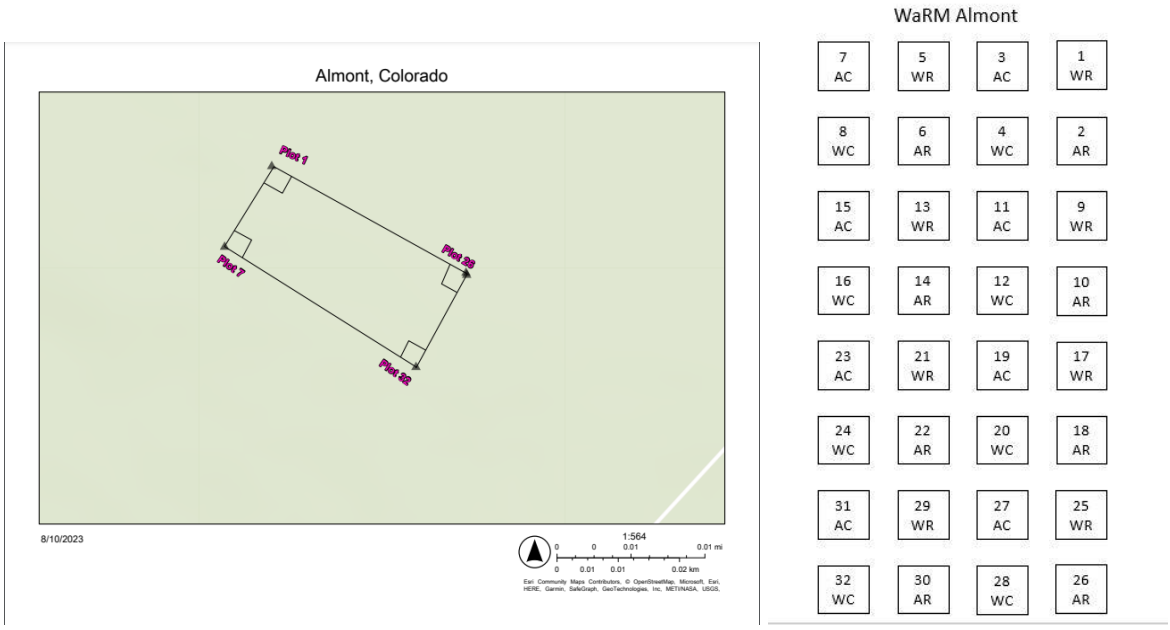

Figure 1. Almont, Colorado

Map of warming and dominant species removal experiment in Almont, Colorado. The layout of the plots can be seen in the right image. WR= Warming Treatment x Plant Species Removal, AR= Ambient x Plant Species Removal, AC= Ambient x Species Present, WC= Warming x Species Present.

The second site is located at the Rocky Mountain Biological Laboratory (RMBL) at 2886 m elevation in the East River Valley of the West Elk Mountains (-106.993354 ° W, 38.962627°N). This is where the accelerated snow manipulation experiment has been conducted. There are five 10 x 10 meter squared paired plots in which the snow manipulation and control plots are side by side (Fig 2.). In total, there are 10 plots in a downhill montane slope. In the winter of 2022, a tarp covered the snow in the manipulated plots until it melted. As a result, snowmelt occurred two weeks before the control plots. The most abundant plant species present in this location were: *Artemisia dracunculus*, *Erigeron speciosus, Erigeron coulteri, Dasiphora fructicosa*, *Delphinium barbeyi, Lathyrus leucanthus, Ligcusticum porteri, Linum lewisii*, *Potentilla pulcherrima, Thalictrum fendleri, Hymenoxys hoopseii, Bromus inermis, Festuca thurberi, Galium septentrionale, Vicia americana* .

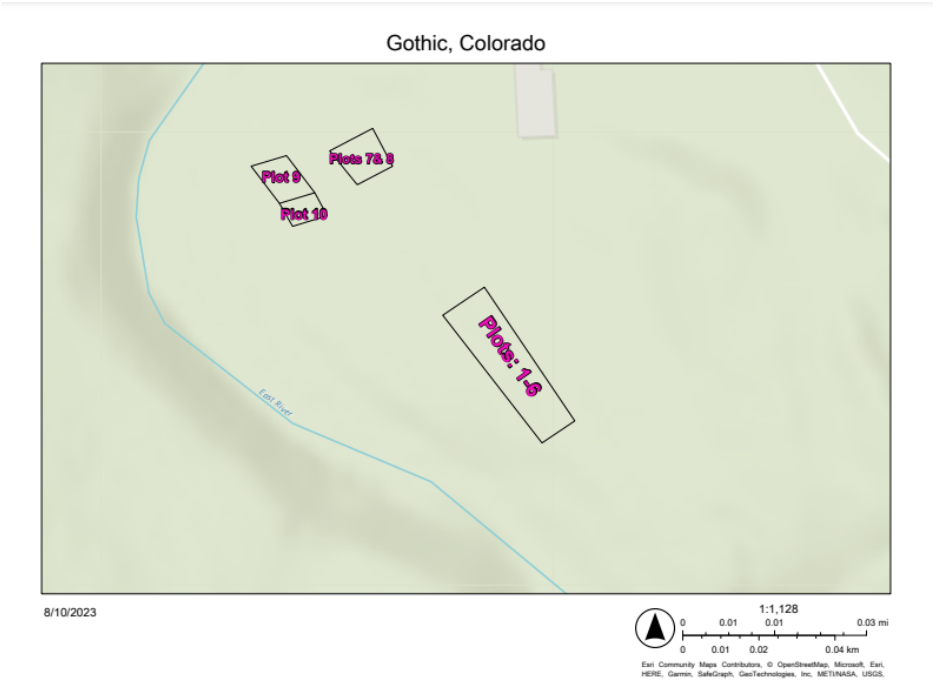

Figure 2. Gothic, Colorado

Map of accelerated snowmelt experiment in Gothic, Colorado. The early snowmelt plots are 2,4,6,8, and 10. The control plots are 1,3,5,7, and 9.

Collection of leaf samples

In both sites, leaf samples were collected from species that represented at least 5% of the cover/plot. For each plant species, four individual plants had 2 leaves snipped off using a pruner and then placed into a sealed sandwich bag. This resulted in the collection of 8 leaves per species. Leaves that were damaged were not collected, only whole and mature leaves were. If the majority of the leaves have been partially chewed by herbivores, then the least damaged were chosen. Leaf samples were collected in peak season at each site. At Almont, this was from mid-June through the first week of July 2023, and at Gothic, Colorado, this was the second and third week of July 2023.

The majority of the plants had one leaf per node, either in an alternative or spiral arrangement. Leaves that contained a lamina, midrib, margin, and petiole were selected for the biomass collection. Meanwhile, whole palmate leaves were collected from plants that obtained them such as *Potentilla congesta, Potentilla pulcherrima,* and *Dasiphora fructicosa.* Palmately lobed leaves were snipped off from the axil. This was common in *Delphinium barbeyi and Geranium viscosissimum.* Only leaflets from individual nodes from the *Artemisia tridentata* were collected. In *Ligcusticum porteri,* leaflets from the bipinnately compound leaf were selected in every plot found. Needle-like leaves from the base of the rosette of the *Eremogone congesta*

plant were collected when the plant was in the vegetative stage. Leaves from the stem were then collected during the budding stage. Grasses such as *Bromus inermis, Festuca thurberi,* and *Alopecurus pratensis* had their leaf blades snipped off at the ligule for collection. Meanwhile, plant species that had leaves in an alternative and compound arrangement such as *Lathyrus leucanthus, Ligcusticum porteri,* and *Rosa woodsii,* had only their leaflets collected.

Leaf mass per area (LMA) and leaf length/area

To calculate LMA, leaves collected that exact day were scanned using an Epson Perfection V500 Photo Scanner. If the collection of leaves and scanning did not occur on the same day, then the samples were placed inside a refrigerator for no more than three days until they were scanned. On the Epson transparent document placer, all leaves from one species per plot were spread evenly alongside a piece of paper with their ID code, date, site, and plot number. Large leaves were cut into pieces and had multiple images. Leaves that were curled up were flattened. Species such as *Potentilla congesta, Potentilla pulcherrima,* and *Dasiphora fructicos* had their leaflets separated from the axil and were arranged right next to each other. The leaflets would count as one whole leaf during image analysis.

The scanned leaf images were utilized to measure the area and leaf length from the petiole to the tip of each leaf. This was done through the ImageJ software analysis program. The set scale for leaf length was (distance in pixels= 1167.1889, known distance 10 cm, pixel aspect ratio = 1.0). To calculate the area, the minimum size ($pixel^2$) was set to 0.2 in the "Analyze Particles" section. Scanned leaves were then placed inside a dryer oven for at least 72 hours at 65 degrees C. After the leaves were dried, each species in a given plot was weighed (g) separately. To calculate LMA, the dry weight of a species in a given plot was divided by its area.

Plant height and quantity of leaves

Using a metric ruler, four individual plants per species in a given plot had their height calculated from the ground to the tallest point in centimeters. Five species that made up 5% of the plot were chosen. This took place during the peak season of each site. For every individual plant that had its height collected, the number of leaves was counted. Leaves that were damaged, newly germinated, and bracts were taken into account.

For the plant species *Ligcusticum porters,* the number of leaflets was counted individually as part of the leaf count due to the difficulty of not being able to distinguish the leaflet from the bipinnately compound leaf. *Dasiphora fructicosa,* which is in the shrub family, had its leaves counted from only one single woody stem that had branched outward. This stem accounted for the plant height. *Artemisia tridentata* was the only shrub in which the number of leaves was counted from individual nodes. Plants that had over 100 leaves were a rough estimate. These species include *Rosa woodsii, Lathyrus leucanthus,* and *Ligcusticum porteri.* Because the leaves are arranged in an alternate and compound manner, patterns of the number of leaves were identified and then multiplied by the number of nodes present.

Chlorophyll content & leaf thickness
To measure SPAD (chlorophyll content) and leaf thickness the instrument PhotosynQ Multispec V 2.0 chlorophyll meter was used. These two measurements were taken from two leaves of four individuals per plant species. Five to four abundant plant species were chosen per plot. Only plant species with leaves wide enough to cover the sensor (about 1cm) were selected. Leaves with a SPAD value far outside the expected range were re-measured.

Results

At Almont, the response of plant height to the experimental treatments depended on the species and the other treatment (warming x removal $F=24.1064$, $p < 0.001$, warming x species $F= 24.9171$, $p < 0.001$, removal x species $F= 4.177$, $p= < 0.001$). Eight out of 15 plant species responded to the treatments in some way. For example, *Achillea millefolium, Erigeron speciosus*, and *Wyethia amplexicaulis* had a significant response to the warming treatment. In some cases, the warm treatment might have influenced the plant height to increase or decrease. In comparison, *Taraxacum officinale* and *Potentilla congesta* had a significant reaction to the removal treatment, where the plant height depended on the dominant plant species' presence or removal. There were also instances where the warm treatment influenced plant height in the removal treatment, such as *Poa pratensis (*Fig 3.). Meanwhile, at Gothic, Colorado there was a significant response of plant height to the species and early snowmelt treatment (treatment $F= 6.4137$, $P=0.01215$, species $F= 45.5450$, $P= <0.001$), but there was no interaction between them. There was a significant difference in plant height between the control and early snowmelt treatment. Plants in the accelerated snowmelt plots had a mean height of 41.4 compared to the control which had a mean height of 45.1. For example, *Delphinium barbeyi* and *Festhuca thurberi* had a slight increase in plant height when it was in the control treatment compared to the accelerated snowmelt (Fig.4).

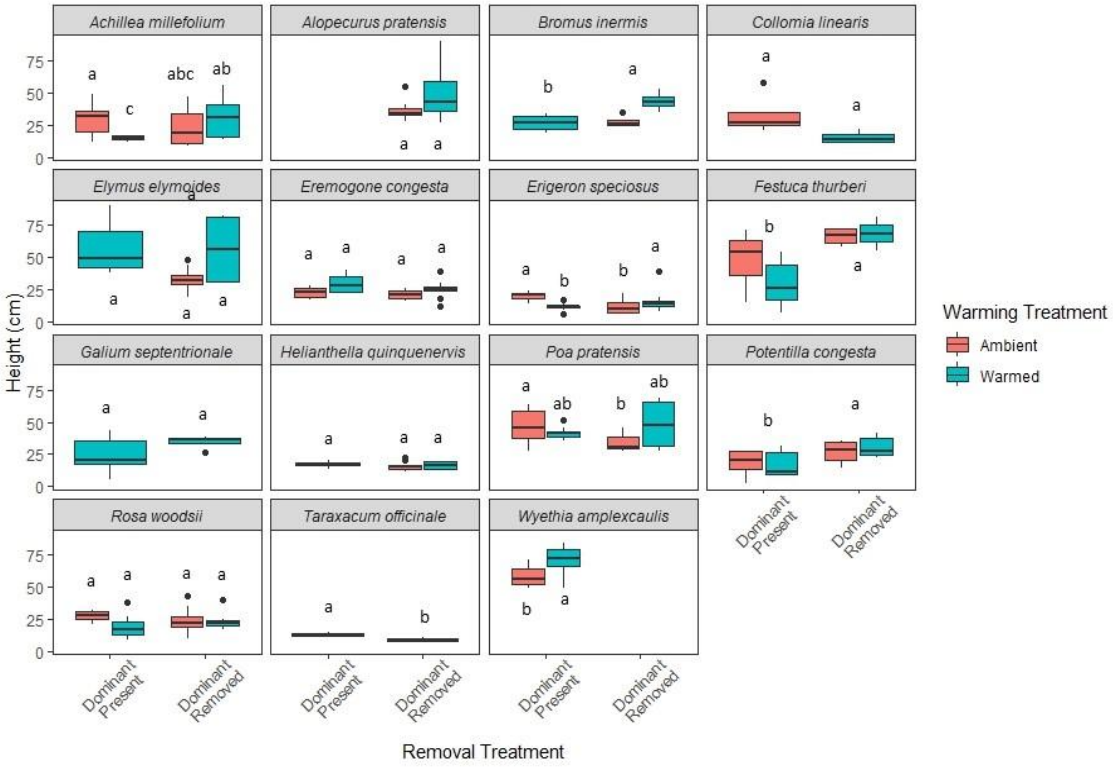

Figure 3. Plant height at Almont, Colorado in response to warming and plant dominant removal treatments.

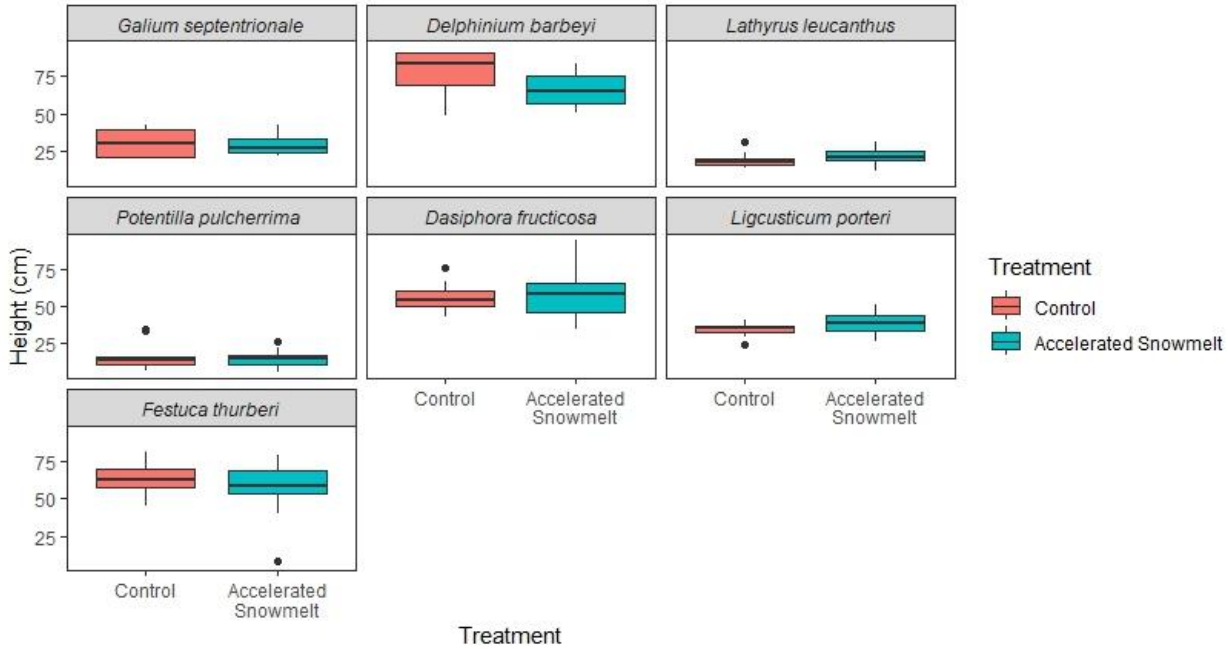

Figure 4. Plant height at Gothic, Colorado in response to accelerated snowmelt manipulation.

At Almont, Colorado there was no significant response of leaf mass per area (LMA) to the experimental treatments, instead, LMA depended only on the plant species (species F= 9.0822, P= <0.001). For example, *Achillea millefolium* and *Festuca thurberi* had a high LMA, and in contrast, *Bromus inermis, Erigeron speciosus,* and *Taraxacum officinale* had a much lower LMA (Fig. 5). On the contrary, at Gothic, Colorado LMA did not vary significantly between species, and did not respond to the treatment (treatment F=0.4409, P=0.5107, species F=1.4180, P=0.2004) (Fig.6).

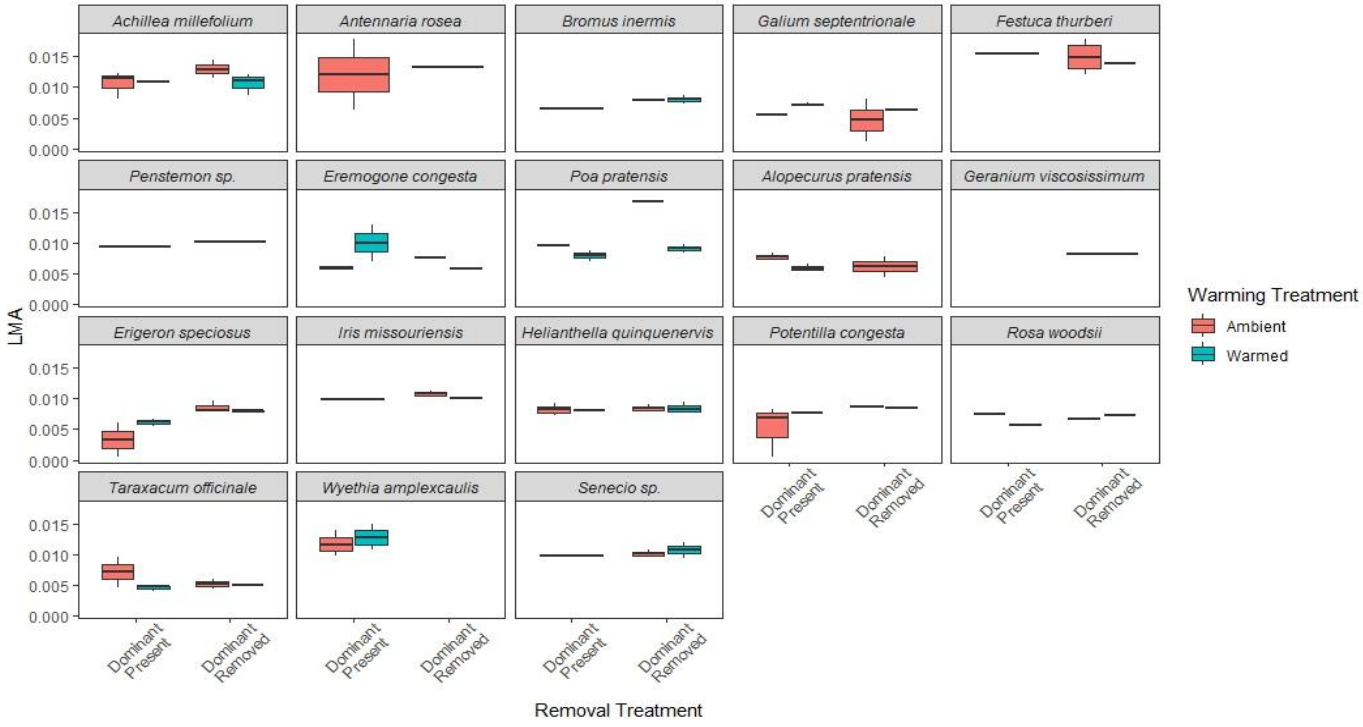

Figure 5. Leaf mass per area (LMA) at Almont, Colorado in response to warming and plant-dominant species removal treatments.

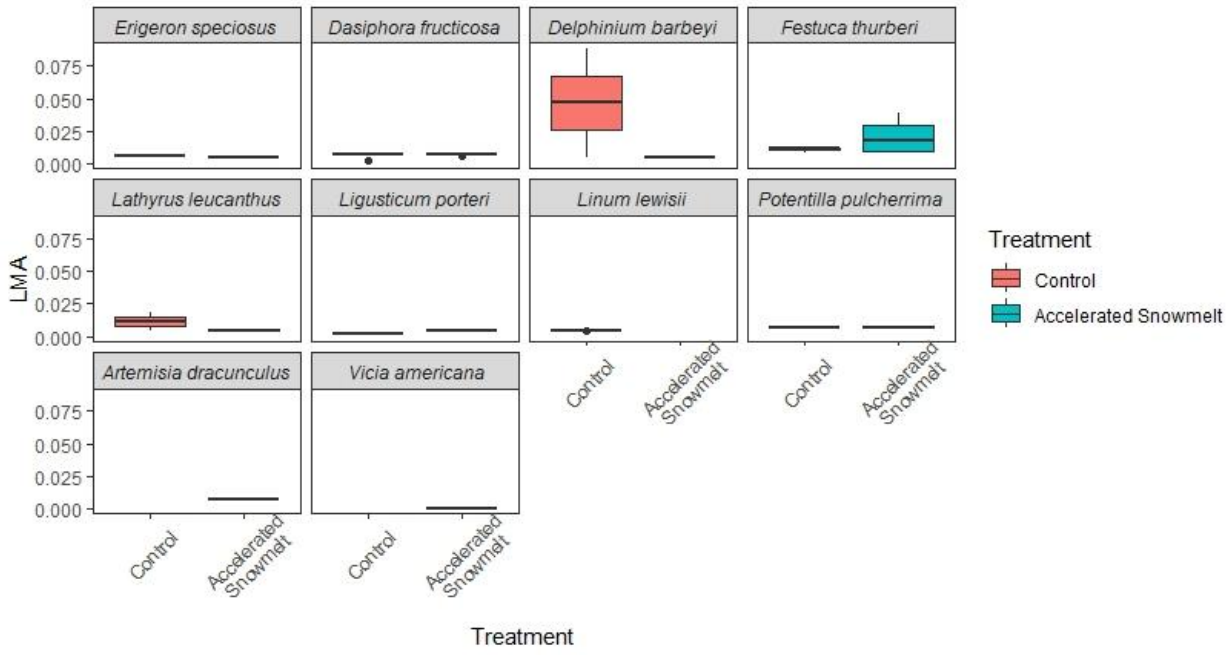

Figure 6. Leaf mass per area (LMA) at Gothic, Colorado in response to accelerated snowmelt manipulation.

Lastly, at Almont, Colorado the response of plant chlorophyll content (SPAD) to the experimental treatments depended on the species and the other treatment (warming x removal x species F= 4.9762, p= 0.002197). Because there was a three-way interaction we can distinguish which plant species were affected by the treatments. For example, *Helianthella quinquenervis,* had a significant increase of SPAD in the warming treatments compared to ambient. In contrast, *Wyethia amplexcaulis* had a high SPAD in the ambient treatment. But in some cases, the warming treatment might increase or decrease the SPAD level depending on the removal treatment. For example, *Taraxacum officinale, Senecio sp., Rosa woodsii, and Erigeron speciosus* were the only plant species in which there was a significant removal response in the warm treatment. For these plant species, the SPAD was higher when the plant dominant species was removed (Fig. 7). In contrast, in Gothic, Colorado there was no significant response of plant chlorophyll content (SPAD) to the experimental treatments, instead, SPAD depended only on the plant species (species F= 10.8244, P <0.001). For instance, Hymenoxys hoopseii had the highest SPAD, while *Erigeron speciosus* had the lowest (Fig 8.).

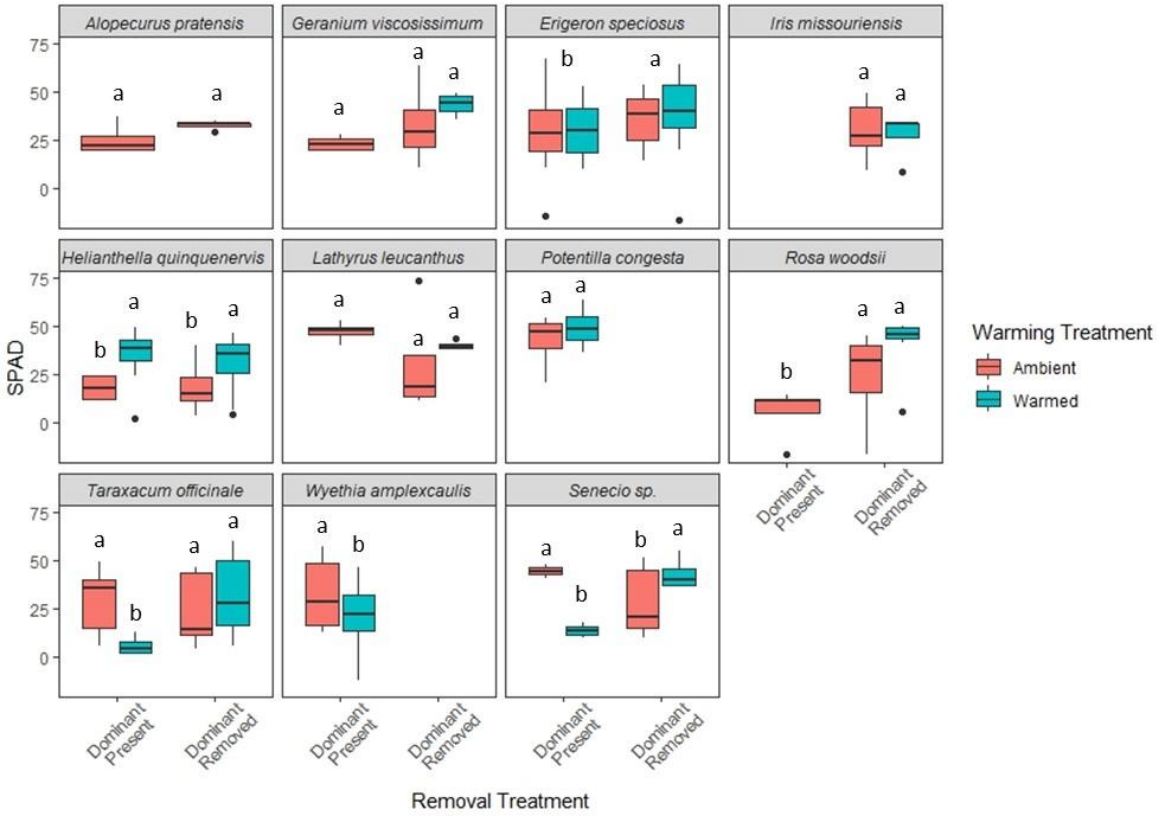

Figure 7. Plant chlorophyll content (SPAD) at Almont, Colorado in response to warming and plant dominant removal treatments.

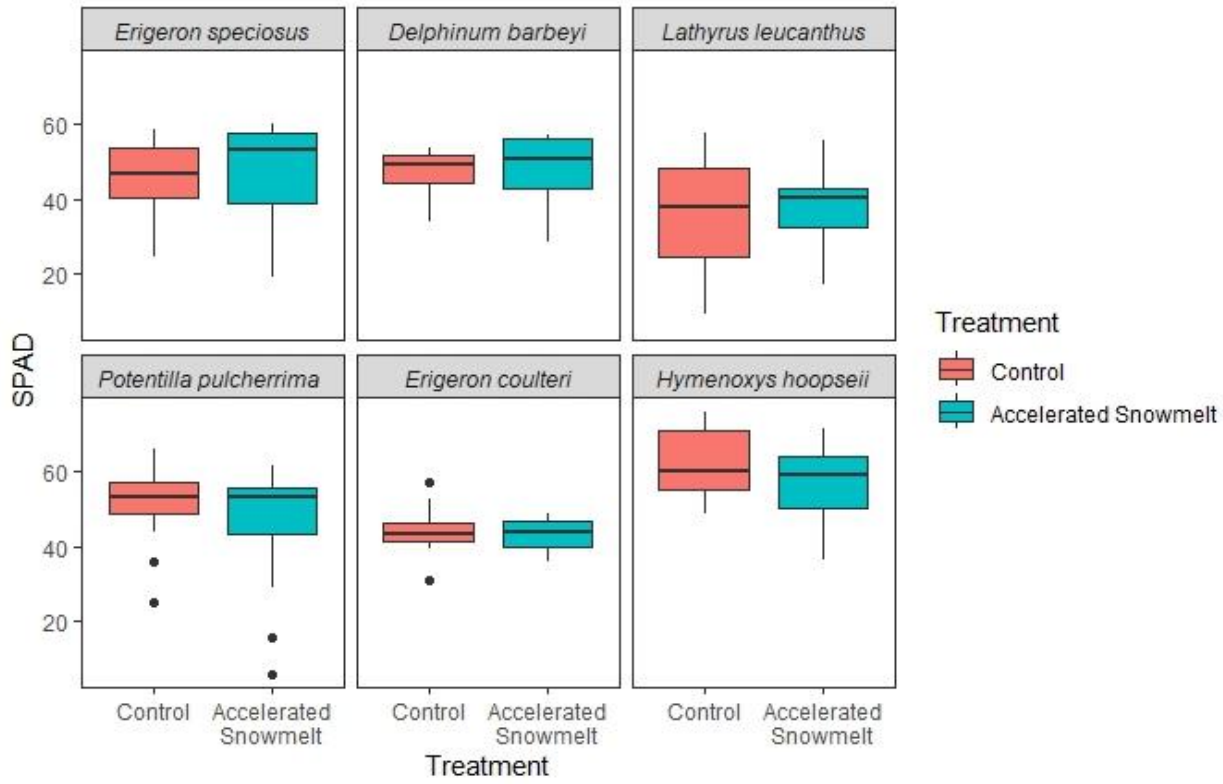

Figure 8. Plant chlorophyll content (SPAD) at Gothic, Colorado in response to accelerated snowmelt manipulation.

Discussion

Leaf mass per area in Almont, Colorado, and Gothic, Colorado

Our results did support one hypothesis that there would be different trait responses across species due to distinct reactions to environmental changes. At Almont, Colorado there was no significant response of leaf mass per unit area (LMA) to warming, dominant species removal, and the warming x dominant species removal treatment. LMA was contingent on the species alone. Similarly, there have been studies, such as the experiments on foliar functional traits in response to warming, that have shown LMA not appearing to be a useful predictor for plant biomass response to warming (Gornish et al., 2014). The positive response of LMA to warming may result from factors important for response to temperature change, such as mass-based nutrient concentrations or plant life span, which can correlate in opposing ways with LMA (Gornish et al., 2014). Another explanation for the lack of an overall treatment effect could be a plant's strategic plan of survival or trade-offs. With increasing temperatures or warming, there might be a high carbon dioxide concentration that is correlated to the rate of photosynthesis. Although there was no positive or negative response to LMA in the warming and dominant species removal treatment, it can be assumed that the increase of 2 degrees Celsius was not enough to denature a plant's enzymes. So species with a long leaf life span will invest additional material

for leaf protection and structural support and consequently tend to a lower leaf photosynthetic rate per unit mass than species with a shorter leaf life span (Edward et al., 2014). Therefore, LMA might not generally be a good indicator of how a plant is performing in its community under different climate scenarios.

Typically, long-lived leaves that have higher costs (maintenance, defense) and fewer benefits such as photosynthates, have a higher potential in lower LMA than species with a shorter leaf life span (Matsuki et al., 2006). We saw that LMA depended on the species alone; those that had a higher LMA, such as *Wyethia amplexicaulis,* are associated with greater investment in photosynthetic tissue, compared to those who didn't such as *Taraxacum officinale.* A study that researched warming responses of leaf morphology among tropical tree species found that all responses to a warmer climate were different among species and between early- and late-successional species groups (Manishimwe et al., 2022). This experimental group found that tropical trees had significant site effects observed for 11 and 12 species in 2018 and 2019, of which six and nine, respectively, declined with increasing warming (Manishimwe et al., 2022). Using the example above, it can be emphasized that LMA usually is correlated with photosynthesis, since thicker leaves with more palisade parenchyma tissue tend to have both higher LMA and photosynthetic capacity (Manishimwe et al., 2022). On the other hand, lower LMA at warm sites has been detected with the decline in photosynthetic capacity observed in late-successional species in the present elevation gradient (Manishimwe et al., 2022). Although these studies were not conducted using montane plant species, they are an important indicator of how other abiotic factors, alongside warming, might influence LMA in a given species if certain conditions are met. Phenological responses, change of sessional groups, and nutrient uptake are all factors that might be correlated in the increase, decline, or unreactive response to LMA.

On the contrary, at Gothic, Colorado LMA did not vary significantly between species and did not respond to the treatment. This could be a result of a large variation of measurements within a species, leading to no detections of a significant difference. Perhaps a larger leaf biomass sample in the snowmelt manipulated and control plots would exhibit a more accurate representation of the response of LMA to accelerated snowmelt. It is also possible that accelerated snowmelt doesn't change a plant's growing environment sufficiently to affect LMA.

Chlorophyll concentration in Gothic, Colorado

Our findings also reveal that at Gothic, Colorado, chlorophyll content (SPAD) was not influenced by the early snow manipulation or the control treatment, instead, it depended on the species of plant. The relationship of chlorophyll content to species can be related to could be explained by the leaf size and shape of the plant. An increase in surface area means that there are a greater number of chloroplasts, resulting in the enhancement of photosynthesis. Although there have not been many studies looking at the response of chlorophyll content (SPAD) in response to early snowmelt, whether it is through experimental manipulation or natural occurrence, we can

use photosynthetic performance to tell us how and why chlorophyll concentrations did not respond to the snowmelt treatments for all the plant species. Contrary to what we found, an experiment that studied snowmelt timing and the regulation of community composition on Alpine plants in the Colorado Rocky Mountains, saw that species richness and foliar cover increased with earlier snowmelt, due to a greater abundance of wide-ranging species present in earlier melting plots (Winkler et al., 2018). Yet, they saw a >50 % decline in net photosynthesis from July to September as soil moisture and plant water potential declined (Winkler et al., 2018). This was a result of stomatal closing due to water stress. Early-season stomatal conductance was higher in wide-ranging species, indicating a more competitive strategy for water acquisition when soil moisture is high (Winkler et al., 2018). Even so, there were no associated differences in photosynthesis or transpiration, suggesting no strong differences between these groups in physiology (Winkler et al., 2018). Similarly, a study relating the spatial and temporal variation in primary productivity (Normalized difference vegetation index; NDVI) of coastal Alaskan tundra found that their measurements indicated an unexpected and progressive decline in vegetation growth as snowmelt advanced each year (Gamon et al., 2013). Sites that emerged earlier were higher and drier and tended to have less productivity measured compared to lower mid-season NDVI values (Gamon et al., 2013). It's suggested that arctic vegetation productivity is not necessarily correlated with the timing of snowmelt but with environmental conditions prevailing early in the growing season before peak production (Gamon et al., 2013). This could explain why an experiment in the Sierra Nevada that studies water availability by depth due to snowmelt, suggests that an environmental condition influencing plant production is primarily soil moisture concentration. It was shown that early snowmelt due to climatic warming and windblown coil reduced near-surface water storage and availability to plants and soil biota (Blankinship et al., 2014). Subsequently, deeper soil water (30-60cm) did not show a statistically significant response to snowmelt (Blankinship et al., 2014). Shallow soil water (0–30 cm), on the other hand, responded strongly to snowmelt timing (Blankinship et al., 2014). The drying effect of accelerated snowmelt lasted 2 months in the 0–15 cm depth and at least 4 months in the 15–30 cm depth (Blankinship et al., 2014). Looking at all these previous studies regarding early snowmelt manipulation, we are informed how early snowmelt has a negative or positive effect on productivity at the beginning of the season. However, water availability declined dues to droughts or competition from plant communities. As a result, photosynthesis and productivity declined. The question of why chlorophyll content at Gothic, Colorado didn't respond to the early snowmelt treatment is still unknown, even though soil moisture and early snowmelt are correlated with one another.

Chlorophyll content in Almont, Colorado

Contrary to what we found at Gothic, Colorado, at Almont, multiple species responded differently in chlorophyll content due to the treatments. For example, *Helianthella quinquenervis,* had a significant increase of SPAD in the warming treatments compared to ambient, whereas *Wyethia amplexicaulis* had the opposite response. A study that observed

first-year tree seedlings found that in *Pinus. koraiensis,* chlorophyll content increased by 20% in warm plots (Han et al., 2015). It was suggested that species-specific growth responses to warming are affected by altered net photosynthetic rate, chlorophyll contents, and leaf area (Han et al., 2015). These results are indistinguishable from an experiment that studied the growth and photosynthetic responses of two coniferous species to experimental warming and nitrogen fertilization(Zhao et al., 2009. It was seen that warming and fertilization alone had a significantly increased biomass accumulation and high photosynthetic performance in both *Picea asperata* Mast. and *Pinus tabulaeformis* Carr. seedlings. As a result, there was an increased chlorophyll content. These consistent results, and perhaps the reasoning why different plant species responded to various warming combinations in the Almont research site, could be that artificial warming and N deposition can influence plant growth indirectly by increased N mineralization and availability, soil acidification, nutritional imbalances, and the leaching of nutrients (Zhao et al., 2009). This is also an explanation of why many plant species, whether they were in the ambient control or warming treatment, had an increase of chlorophyll when the dominant species, *Wyethia amplexicaulis,* was removed. The absence of this species reduced the issue of competition for light source availability and increased the richness of macronutrients which are all essential for plant growth and photosynthesis.

Plant height in Almont, Colorado

Plant height in Almont, Colorado had a significant reaction based on the species and treatment(s) involved. For example, *Taraxacum officinale* had a higher plant height when the dominant-plant species was present, whereas *Poa pratensis* had an increase in height when it was in the warm and in the plant-dominant removed treatment. Similar results have been reported in that plant traits respond differently, especially among plant communities (Baruah et al., 2017). Most species tended to be taller and had larger leaf widths and lengths in warmed plots, while there were species that had significantly negative responses in at least one trait (Baruah et al., 2017). In support of this, a study measured the relative importance of neighbors and abiotic environmental conditions for the population dynamic parameter of *Thanlictrum alpinum* and the sedge *Carex vaginata*. They found that the responses of the two target species to the removal treatment of the general neighbor vegetation were less pronounced than their responses to the removal of dominant *Dryas octopetala* examined in previous studies (Klanderud et al., 2005). This suggests that one dominant species may affect the population dynamics of other species more than the net effect of all other species in the community in concert (Klanderud et al., 2005). As a result, biotic interactions may affect alpine plant populations and their structure alpine plant communities. Furthermore, the effects of neighbors and abiotic environmental changes on alpine plant growth may depend on the species identity of the neighbors (Klanderud et al., 2005). Other studies reveal that contrasting abiotic and biotic controls over dominant peatland plant growth, suggest that community composition and carbon cycling could be modified by climate and vegetation change (Walker et al., 2015).

Conclusion

Most of the plant traits had no overall significant response to the warming, dominant species removal, and early snowmelt treatments, rather, the response relied on the species and/or the combination of treatments. No consistent patterns can be seen with these traits, although they directly affect one another. This further proves how complex plant traits are and how different they might vary in similar environmental locations. Yet, aboveground traits are the most visible indicators of how plant communities are changing due to the rapid disruption of environmental balances. These variations of plant trait responses can help us understand any potential competitive interactions that montane plant communities might face. Because plant traits are a direct link to plant fitness, studying plant responses to warming, earlier snowmelt, and the presence of dominant species at a species-specific and community level might express favor to long-term potentiation. Although most traits in this experiment relied solely on the species in a certain experimental treatment, there might be other abiotic factors that could potentially disrupt functional plant responses and performance. This includes water availability, droughts, and the fluctuation of temperatures. We know that there is a direct association between increasing temperature late in the year to early snowmelt in the spring. If snowmelt dates begin earlier than in previous years, then the way aboveground plant biomass might completely change in ways that we cannot predict or comprehend. The photosynthetic rate can change in the same plant species affecting productivity before and after peak season. Water can become scarce, this can take in the form of precipitation and soil moisture, resulting in the difficulty for plants to absorb nutrients and photosynthesize. Thus, these climate change scenarios might favor a wide range of species that are adapted to a set of temperature and moisture restrictions. Trees and shrubs, which have deeper roots, can access water compared to plants that have shallow roots. The abundance of plant species diversity will decrease if species cannot undergo plasticity in a given time. Those who do exceed to adapt to rapid changes in the environment will become a dominant species overtaking space, light sources, and nutrients found in the soil. For future studies, it is best to observe plant traits in long-term studies in various biomes, like tundras, grasslands, and temperate rainforests, to find a collective response to climate change manipulations significant to that region. On a smaller scale, further study can be done to observe aboveground traits in montane meadows with similar warming, snowmelt, and dominant plant species removal conditions with additional testing that can be beneficial to compare plant responses. This can include analysis of organic matter content, microbial activity, root activity in various species, and nutrient analysis. Overall, understanding how plant traits might respond to future environmental conditions can help us comprehend these responses and predict how plant communities in montane meadows might change under future climate scenarios.

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