

**Floral Albedo as a Response Factor of
Climate Change,
A case study in
*Helianthella quinquenervis***

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ABSTRACT

Because phenology and climate are linked, studying the consequences of shifting phenology can help scientists understand the systems that make up current climates and construct future ones. In the Rocky Mountains, climate change has led to earlier snowmelt, an event that triggers the start of the growing season. When *Helianthella quinquenervis* flowers early, the harsher abiotic conditions of the early growing season can damage the buds that would have otherwise flowered that year. We hypothesize that locations with a dense population of *H. quinquenervis*, like the population located in Maxfield Meadow, are now subject to drier conditions and increased water stress in years when *H. quinquenervis* flowers are frosted by the low night temperatures of the earlier growing season. In this study, *Helianthella* bud removal simulated the bud frosting effect. We hypothesized that the lack of *H. quinquenervis* changes the overall color of the meadow from yellow to green, decreasing the amount of light that the meadow can reflect, decreasing soil moisture and increasing plant water stress. We found that *Helianthella* flower petals reflect significantly more light than leaves, and this effect persists at the plot-level. The data show that the effect of reduced albedo on soil moisture is most likely to occur during sunny conditions. It also shows *Helianthella* removal did result in a trend supporting the initial hypothesis, with slightly increased water stress in the removals, although this effect was not significant. *Helianthella* was not blooming as densely as has in the past years, and effects of reduced albedo on soils and plants may be stronger when floral density is higher.

INTRODUCTION

Climate change is one of the most interwoven problems that scientists face today. The complexity of climate change can be tackled piece by piece by looking at ecological case studies that reveal key consequences of climate change (Root 2003). Specifically, we will be examining flowering phenology shifts. It is now accepted that phenology is a widespread response to climate change, and understanding phenological shifts is central to understanding the biological effects of climate change. In sub-alpine regions, flowering phenological shifts are dependent on the timing of snowmelt and the temperatures of the previous spring (Richardson et al. 2013). By studying flowering phenology and the possible feedback systems where it plays a central role, the possibility of making models that can predict the consequences of future climate shifts becomes more attainable.

Climate change has led to higher temperatures in sub-alpine regions, resulting in earlier snowmelt. In years with early snowmelt and increased temperature, *Helianthella quinquenervis*, the aspen sunflower (Asteraceae), flowers early (Inouye 2008; Iler et al. 2013). While flowering early lengthens the growing season for montane wildflowers, it also exposes them to the harsh abiotic factors that accompany early spring (Inouye, 2008). Specifically, the low temperatures of June nights increase the likelihood that developing *H. quinquenervis* flower buds experience frost damage (Inouye 2000). If a significant portion of *H. quinquenervis* experiences frost damage, the albedo of the meadow may decrease as the meadow that was once blanketed in yellow flowers turns green (Richardson et. al 2013, Picture 1). A green surface absorbs more sunlight and heat than a yellow one, which could lead to even warmer and drier soils in years that are already warm and dry. Indeed, previous work has shown that soil moisture decreases and soil temperatures increase in areas without sunflowers compared to areas with sunflowers

(Iler, unpublished data, 2015). In addition to this possible feedback system, the meadow experiences lower levels of water moisture due to increased temperature. Lastly, the heat and the dryness of the soil may increase the water stress in *H. quinquenervis*.

This study examined if (1) *H. quinquenervis* flowers influence the albedo of Maxfield Meadow, and (2) if climate change creates a feedback loop involving, albedo, soil conditions (moisture and temperature), and water stress.

METHODS

Experimental Setup

Twenty 2x2 m plots located in Maxfield Meadow at the Rocky Mountain Biological Laboratory in the Colorado Rocky Mountains were used in this project (Figure 1). In order to control for varying environmental conditions in Maxfield Meadow, the plots were paired according to likeness. One plot was a control plot and the other pair had all of the *H. quinquenervis* flowers removed in order to simulate the appearance of the meadow when the flower buds are frosted. The heads of the flowers were removed below the receptacle. The albedo of both ray flowers and leaves was measured during peak flowering using the ASD HandHeld2 spectroradiometer, which measures the amount of light reflected from a sample across the visible and near IR spectra (values range from 0 to 1). Ten leaf samples and 10 flower samples were used to calculate the mean reflectance of both tissue samples. In order to get an accurate measurement of the albedo of *H. quinquenervis* ray flowers, the ray flowers were picked off and taped down, making sure to handle the flowers with forceps to decrease any damage to the samples. Petals were taped to a sheet of white paper in order to create a sample large enough to fill the chamber of the spectroradiometer. Volumetric soil moisture was measured weekly using a FieldScout soil moisture probe with 3 in. prongs. We took four soil moisture measurements per plot. The plots were divided into four subplots, and soil moisture was measured in the middle of each subplot. During the week of peak flowering, soil moisture was measured twice. Soil temperature was measured at two soil depths (4 cm and 8 cm) with HOBO data loggers. Water stress will be measured in two different ways. Leaf water pressure was measured using a pressure chamber (PMS model I505D) for an instantaneous measure of water stress. Additionally, the carbon-nitrogen ratios of the leaves will be measured on leaves collected after the plants have flowered but before they senesce.

Analysis

We performed all of the analyses in R version 3.3.2 (R Core Project, 2017). We took advantage of the fact that our experimental design was paired by using paired t- tests. Paired t-tests were used to compare mean soil moisture and mean water stress between the control and removal plots. A one-sided t-test was used to see if there was a difference in reflectance between removal plots (assuming the plots are 'all green', using mean leaf reflectance) and plots with *Helianthella* flowers. In addition to the paired t-tests, we also used more complex statistical models with increased power to detect differences between treatments when appropriate. For reflectance, a linear model was used (ANCOVA) with reflectance as a response variable, and treatment, wavelength, and their interaction as predictors. In the future, the temperature data will be analyzed to see if there is a difference in mean temperature between the control and removal plots using a linear mixed model with temperature as a response variable (mean across

hours), treatment as a predictor, and date as a random intercept term to account for repeated sampling across dates. Specifically, this analysis will focus on days that were sunny ($>20,000$ lux) when *Helianthella* was flowering.

RESULTS

A t-test showed that there is a significant difference between the albedo of the flower and the leaf samples ($t = 61.481$, $P < 0.001$, Figure 2). Flower petals had an albedo of 0.61 while *Helianthella* leaves had an albedo of 0.29. This difference in albedo between flower petals and leaves was reflected at the plot level. Removal plots exhibited lower levels of albedo than control plots ($t = -2.32$, $\text{DOF} = 9$, $P = 0.045$, Figure 3). Control plots had a mean albedo of 0.293 while removal plots had an albedo of .29. The type of the tissue (*i.e.* flower or leaf) being analyzed was not the only independent variable that influenced the mean reflectance of the leaf and the flower samples. This is due to the nature of the HandHeld2 spectroradiometer. The spectroradiometer emits a spectrum range onto the sample (from infrared to visible light), and records how much the sample is reflecting at each wavelength of that spectral range (Figure 4). A linear regression model explains that both wavelength and tissue type are significant predictors of mean reflectance, in addition to their interaction ($R^2 = .77$, $F = 1690$, $P < 0.001$; Table 1). Because the data loggers are going to be in the ground until the end of the flowering season, we have not had the chance to collect them and analyze the data. Once we have collected the data loggers, we will use paired t-tests in order to compare the temperature between control and removal plots. We will restrict the analysis to days that are sunny in addition to days when *H. quinquenervis* is blooming.

There was only one day when soil moisture of removal plots was higher than at control plots (Figure 5, Table 2). We will also conduct a more in depth analysis of soil moisture, accounting for resampling and weather data. While we predicted that plants in the removal plots would be under more water stress, there was not a significant difference in water stress ($t = -1.2884$, $P = .2297$, $n = 10$ pairs). Despite this fact, the plants in the removal plots are under somewhat more stress than removal plots, seeing as the trend supports our initial hypothesis (Figure 6). In the future, we will collect more extensive measurements on plant water stress by collecting more plant samples. These samples will be sent back to Northwestern University, Chicago, and their carbon-nitrogen ratios will be analyzed. The measurements from the PMS gave instantaneous measurements of plant water stress, but the carbon-nitrogen ratio of the samples will tell us how stressed the plants were over the course of the field season.

DISCUSSION

The main focus of this study was to explore floral albedo as a response factor to climate change, and how a decrease in floral albedo changes the abiotic conditions for the aspen sunflower. The frosting of *Helianthella* buds, a consequence of climate change, was simulated by removing *Helianthella* flower buds. We predicted that the *Helianthella* removal treatment would result in a subsequent decrease in albedo in the *Helianthella* removal plots, resulting in a decrease in soil moisture and an increase in temperature. The results of the experiment support the hypothesis that flower removal lowers the albedo.

The difference in reflectivity between the flower and the leaf samples translated into a difference in reflectivity between the control and removal plots, suggesting that the albedo of

the meadow can be altered by frost damage. This difference in albedo was associated with reduced soil moisture in removal plots on one sampling date during peak flowering (July 24), suggesting that the July monsoon rains may compensate for warmer soils in removal plots (Iler, unpublished data). Along these lines, plant water stress did not differ between treatments.

Some might argue that the *Helianthella* flower removal would negatively impact the physiology of the plants in the removal plots resulting in increased water stress. Contrarily, we would expect the plants that are flowering to be under more water stress than the plants in the removal plots. This is because flowering plants have increased water demands in order to maintain their flowering status (Galen et al., 1999). Additionally, our analysis shows that there was no effect of flowering status or an interaction between flowering status and treatment on water stress, which suggests that clipping did not have unintended consequences on water stress. Nevertheless, clipping buds might have induced a response to herbivory, which could have unintended consequences on water stress (Freeman et al., 2003).

Across all of the response variables, it is apparent that there is not a large difference between the abiotic conditions in the control and removal plots. We predict that this is due to the decrease in *Helianthella* flower density in Maxfield Meadow compared to 2015, when there was more evidence of effects of flower removal on soil temperature and soil moisture (Iler, unpublished data). A total of 5.7% of the plots were covered with *Helianthella* in 2015, while only 1.09% of the plots was covered in *Helianthella* in 2017 (mean of. 95.7 flowers vs. 18.4 flowers at peak flowering, respectively). This is likely due to the differing weather conditions between 2015 and 2017. This could be explained by weather data collected by Billy Barr, and the fact that time and abundance of flowering depend on the previous winter's snowpack. Timing and abundance of flowering have been shown to be positively correlated with total winter snowpack for the sub-alpine wildflower *Delphinium barbeyi* (Inouye et al. 2002). The winter before the 2015 growing season, the study site received 1177 cm of snow while only getting 837 cm of snow the winter before the 2017 growing season. When this snow melts, this water supply determines how much water the wildflowers have at a critical time, thus determining the abundance of flowers blooming that year. Weather data provided by Billy Barr shows similar May temperatures for 2015 and 2017, suggesting that the difference in flower abundance is explained solely by snowfall and snowpack.

While the plants in the removal plots were under only somewhat more stress than the plants in the control plots, this data shows a trend that supports the initial hypothesis. The data from the PMS suggest that carbon-nitrogen ratios could show a significant difference in soil moisture between the control and removal plots. In the context of the soil moisture data, it is also important to note that the measurements from July 24th were taken during peak flowering. This is when we would expect to see the strongest response to *Helianthella* removal. This data supports the findings of the Iler 2015 lab, since the effect was only seen during peak flowering and was probably influenced by hot and sunny weather conditions. When weather conditions are wetter, the soil in the plots is more likely to be saturated, regardless of the assigned treatments. Wetter conditions are also often paired with cloud cover, meaning that sunlight is no longer part of the equation. Without any sunlight, the albedo in the removal and control plots is no longer a factor, and we cannot see the effect of *Helianthella* removal. When conditions are hot, dry, and sunny, albedo is at play as to how much moisture the soil can hold.

Despite the sharp decrease in the flower density of *H. quinquenervis* between the years 2015 and 2017, we still see that control plots are able to reflect more light than the removal plots. This leads us to believe that it does not take a year with high flower density for the removal treatment to impact the subsequent soil moisture and temperature of the meadow. The effects of climate change on phenology are well-documented (Inouye 2008), but we are just beginning to understand the consequences of shifts in flowering time. For example, the biotic consequences of shifted flowering times have received a lot of attention with regard to the phenological mismatch hypothesis (McKinney et al., 2012), but less is known about the abiotic consequences of shifted flowering times. The fact that albedo changes with the changing phenology of the meadow makes it an important response variable, and exemplifies how shifting phenology has substantial consequences.

Tables and Figures

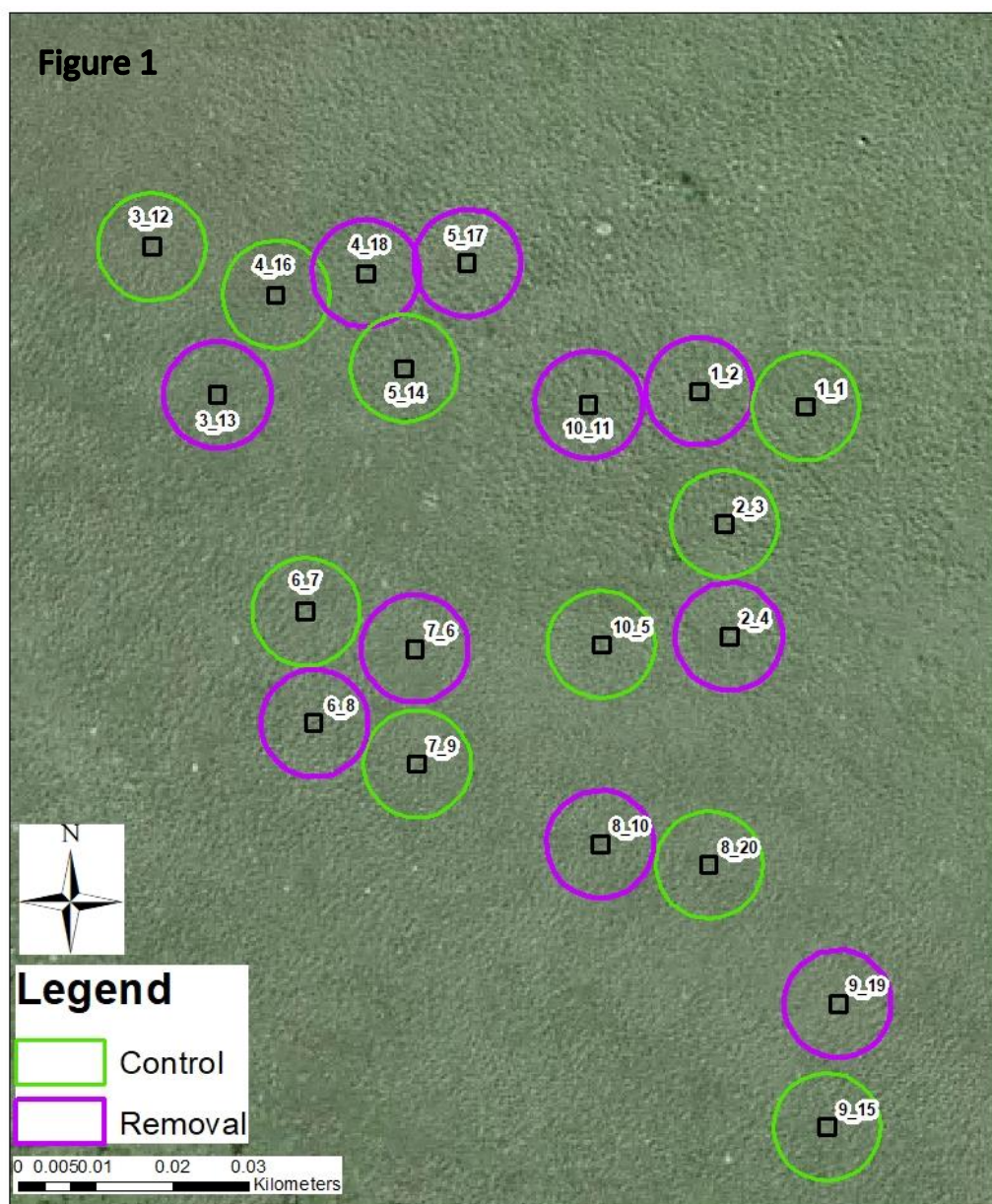


Figure 2

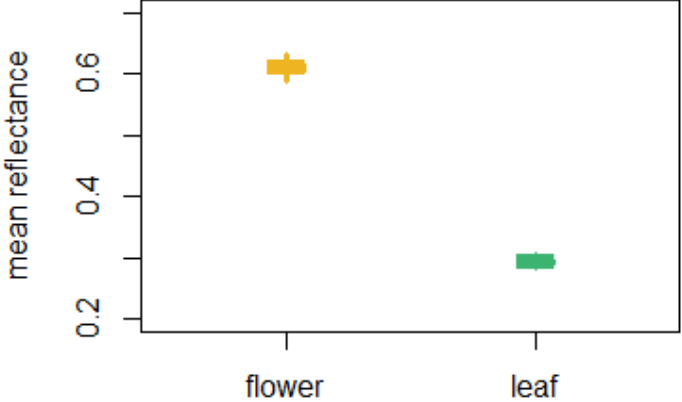


Figure 3

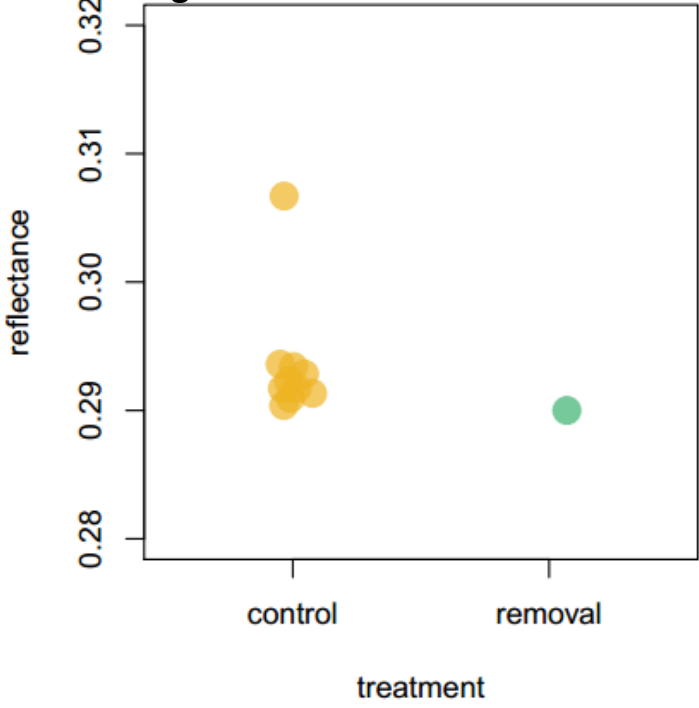


Figure 4

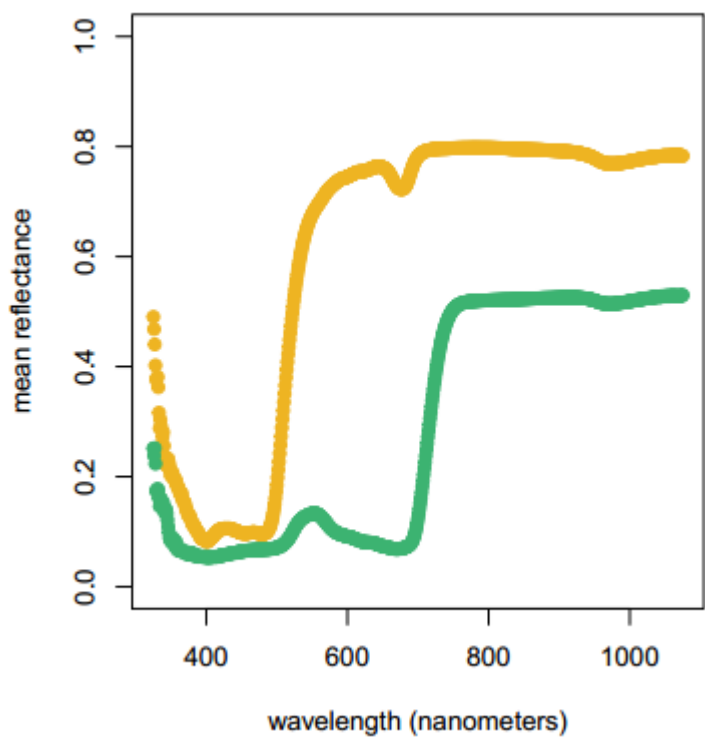


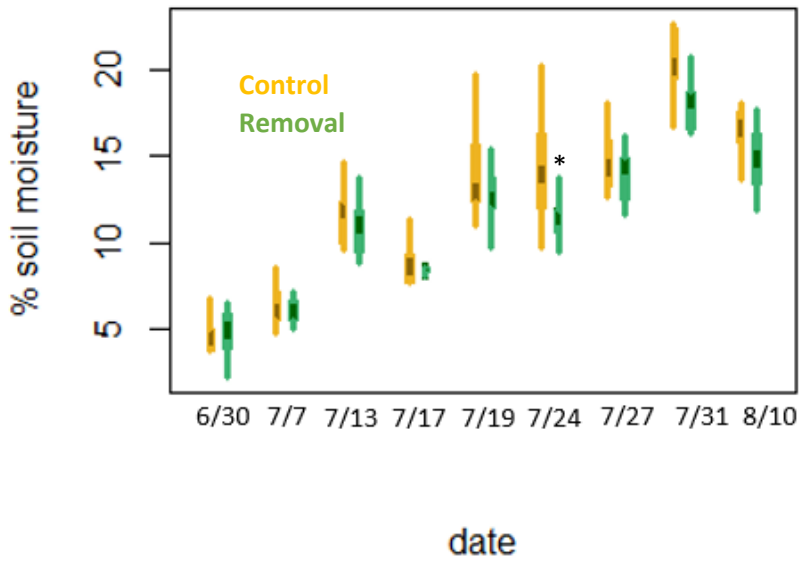
Table 1

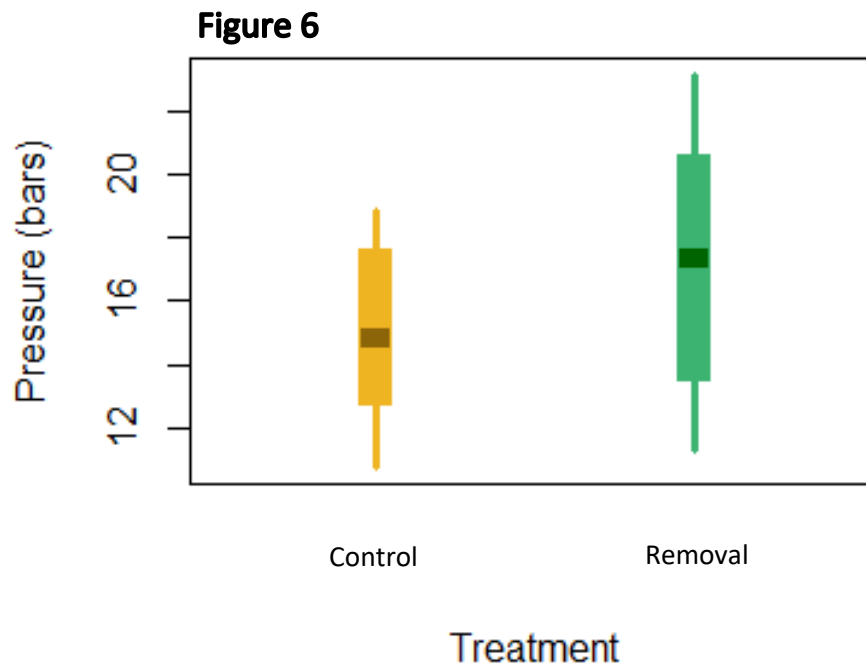
Coefficients	Estimate	Standard Error	T-Value	P-Value
Intercept	-9.092e-02	5.454e-03	-16.67	< 2e-16
Tissue Type	-2.252e-01	7.713e-03	-29.20	< 2e-16
Wavelength	9.981e-04	7.443e-06	134.11	< 2e-16
Tissue Type: Wavelength	-1.284e-04	1.052e-05	-12.20	< 2e-16

Figure 5

Date	T-Value	Mean % Difference	P-Value
6/30	-0.17872	-6	0.8621
7/7	0.31243	16	0.7618
7/13	0.88326	57	0.4001
7/17	0.48287	20	0.6407
7/19	1.1755	118	.27
7/24	2.7979	199	0.02078
7/27	1.5256	149	0.1615
7/31	1.9243	186	0.08646
8/10	2.0923	146	0.06594

Table 2





Pictures

- (1) The leftmost picture shows Maxfield Meadow during a year when *H. quinquenervis* is flowering normally. The rightmost picture shows Maxfield Meadow in a year where *H. quinquenervis* is flowering earlier and the buds are frosted

Figures

- (1) This figure shows a map of the paired plots located in Maxfield Meadow.
- (2) This figure shows that there is a significant difference in mean reflectance between all of the flower and the leaf samples
- (3) This graph the result of a t-test comparing the mean reflectance of each plot with the approximate mean reflectance of the removal plots. It is assumed that because the meadows have a mostly green cover, it would have an albedo similar to the mean reflectance of the leaf samples. The control plots reflected significantly more light than removal plots.
- (4) This graph shows the mean reflectance for the flower and the leaf samples across a spectrum range (380nm-780 nm). The mean reflectance of a flower is shown to be significantly higher than the mean reflectance of a leaf. The table shows the results of an ANCOVA test for the flower and leaf samples. Wavelength, tissue type, and the interaction between the two are significant predictors of reflectance
- (5) This table show results of paired t-tests between control and removal plots for every day that soil moisture measurements were recorded. There was only one day (July 24th) that

removal plots had drier conditions than control plots/ this figure shows a series of t-tests between the control and removal plots from week to week. An asterisk shows when there was a significant difference between the plots.

- (6) This figure shows the result of a t-test comparing water stress between the control and the removal plots.

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