

# Long-term Population Trends and Environmental Attributes of the Imperiled Chapin Mesa Milkvetch (*Astragalus schmolliae*)

2019



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Cover photo: Chapin Mesa Milkvetch on Chapin Mesa,  
by Renée Rondeau 2019.

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WARNER COLLEGE OF  
Natural Resources  
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## ABSTRACT

In 2019, the Colorado Natural Heritage Program repeated Anderson (2001) density estimates for the entire milkvetch (*Astragalus schmolliae*) population on Chapin Mesa within Mesa Verde National Park (MEVE). A total of 197-100 x 10 m belt transects were established in 2001 (one year before a fire burned nearly 40% of the population) and repeated in 2019. A subset (44) of these transects were initially monitored in 2003 and then every year since 2011. In addition we continued to collect annual data from 22 permanent demography plots that were established in 2015. We collected reproductive effort, recruitment, mortality, and vigor data within the 100 m<sup>2</sup> permanent plots, of which half are in burned areas and the other half in unburned pinyon-juniper woodlands. Within each demography plot, a small subplot (1 m<sup>2</sup>) was established to follow marked individuals between years as well as throughout the summer (June – August). Results strongly suggest the positive effects of fire that were originally seen after the 2002 Long Mesa Fire are waning or have reversed. It appears that the species initially benefitted from the large-scale burn, resulting in a high recruitment rate. However, by 2015-2019 the recruitment and reproductive output in the burned area was far below that in the unburned woodland, suggesting that while this species is adapted to survive fires, it is essentially a woodland species. In 2019, the Chapin Mesa population within the burned areas had less than 40% of the expected density compared to the unburned transects which were slightly above expected density. Seedlings were all but absent in burned areas and abundant in unburned transects (over 6000 seedlings). The only 2015-2017 seedlings to survive the 2018 extreme drought were those that emerged in 2015, that is, the 2016 and 2017 seedlings did not survive the extreme drought.

Soil analysis was conducted for 12 of the 22 demography plots to assess attributes that may impact the milkvetch density and reproductive output. We found that there was a strong correlation between plant density and organic matter. Sites with high organic matter were more likely to have high milkvetch density. Organic matter increased with proximity to cliff edges as well as further south (down-slope), whereas the top of the mesa and the northern sections had less organic matter and lower milkvetch densities.

The density, reproductive, and vigor data allowed us to make several inferences with varying degrees of confidence:

1. We have high confidence that annual variation in density counts are strongly correlated with winter precipitation. Average and above average winter precipitation provides the highest spring emergence, while winter droughts produce very low emergence. Even in moderately wet years, not all plants emerge, especially in burned plots.
2. We have high confidence that density in burned and unburned areas has changed over time. The initial post-fire response in burned areas was positive and allowed a flush of reproduction that was above that of unburned areas. This positive response began to wane around 13 years post-fire.
  - a. Age class ratios differ between burned and unburned plots (2015-2019) as burned plots are skewed towards immature and adult plants while unburned areas include seedlings and yearlings, in addition to immature and adult plants.
  - b. In 2017 and 2019, mortality of immature and adult age classes was higher in burned vs unburned plots.

3. We have high confidence that the following 2015-2019 reproductive attributes were lower in burned plots vs unburned plots:
  - a. *Seedlings/adult*: 5-fold reduction in seedlings/adult in burned vs unburned (a median of 0.2 seedlings/adult in burned vs 1.0 seedlings/adult in unburned)
  - b. *Yearlings/adult*: 10-fold reduction in yearlings/adult in burned vs unburned (a median of 0.04 yearlings/adult in burned vs 0.40 yearlings/adult in unburned)
  - c. *Proportion of reproducing adults*: Two-fold reduction in the proportion of adults that were reproducing in burned vs unburned (median was 0.4 vs 0.7, respectively)
  - d. *Total fruits*: 2.5-fold reduction in fruits that were produced (2015-19) in burned vs unburned (1259 vs 3143, respectively)
4. We have high confidence that over 95% of the seed germination occurs in April-May and that seedling survival in burned areas in 2015-17 was significantly lower than that in unburned areas.
5. We have moderate confidence that burned areas have higher shallow soil temperatures from May-August than unburned shallow soils.
6. We have moderate confidence that there is little difference in winter season deep soil moisture between burned and unburned areas, at least in wet years.
7. We have high confidence that cheatgrass, western wheatgrass, and smooth brome are abundant in burned areas and absent in unburned areas.
8. We have high confidence that spatial variation in density is associated with clay content and organic matter, with high densities tightly associated with high organic matter.
9. We have low confidence regarding if or when the recruitment and mortality in burned areas will begin to parallel unburned areas.

Our observations present multiple hypothesis as to why the burned areas have become less favorable to Chapin Mesa milkvetch, including: 1) seedlings are suppressed due to competition for soil moisture from abundant grass cover, especially cheatgrass, western wheatgrass, and smooth brome, 2) shallow soil temperatures during the growing season are significantly higher in burned areas, which exacerbates depletion of soil moisture, especially when coupled with abundant grass cover, 3) lack of bare ground in burned areas inhibits ground-nesting bees, which may be important pollinators, 4) without tree cover for protection, late frosts are more likely to kill flowers in the burned area as well as increase peak daytime soil temperature. Currently the burned areas are dominated by grasses, both native and non-native, with some shrub recovery evident but virtually no tree regeneration. It is well understood that tree regeneration of pinyon pines, post-fire, is a slow process that may take many decades. The invasion of cheatgrass, smooth brome, and western wheatgrass may further slow this succession. The transition back to a woodland appears to be important for Chapin Mesa milkvetch. Projected climate change is likely to increase the fire risk in the remaining woodlands, thus post-fire management plans that discourage cheatgrass, smooth brome, and western wheatgrass may assist with a quicker transition from grassland to shrubland to woodland. In order to maintain the current population in the unburned area, preventing the remaining old-growth pinyon-juniper woodland from a catastrophic fire is a high priority. Developing a post-fire management plan that takes into consideration the control of cheatgrass and a beneficial seed mix is also important.



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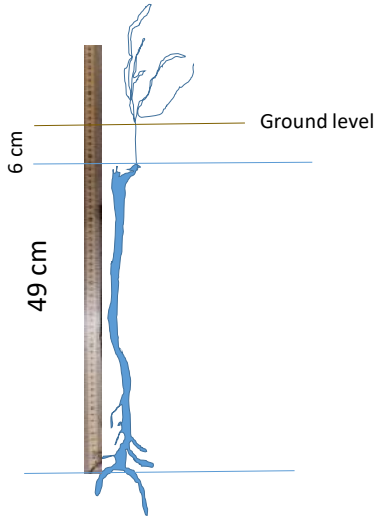


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# INTRODUCTION

## Species and Site Information



Chapin Mesa milkvetch (*Astragalus schmolliae* C.L. Porter), a member of the legume family (Fabaceae), is a globally rare species, constrained almost entirely to Chapin Mesa within Mesa Verde National Park (MEVE) and the Ute Mountain Ute Tribal Park, with small outlying populations on neighboring Park Mesa, east of Chapin Mesa and the West Chapin Spur. Its habitat is dense old growth pinyon-juniper between 6,500 and 7,500 feet in elevation on deep red loess soil of the mesa tops. Like many rare plants, it is globally rare, but locally abundant throughout occupied habitat. Chapin Mesa milkvetch (CMM) is second only to mutton grass (*Poa fendleriana*) as a dominant understory plant of the pinyon-juniper woodland (Colyer pers. com. 2002). It is a deep tap-rooted herbaceous perennial (Friedlander 1980) that goes dormant during the winter. The above-ground biomass withers away in the fall, and new sprouts arise in the spring from the below-ground woody caudex. In favorable years, both flowers and fruits are present in late May. The species is characterized by

showy, bee-pollinated white flowers and downward curving pods. After severe winter drought years, most plants remain dormant during the growing season (no above ground stems). Seedlings germinate in April and May, and occasionally in June if there is adequate precipitation to maintain moist shallow soil. Seedlings rapidly develop long tap roots to reach the deeper soil moisture.

The species is considered highly vulnerable to climate change (Handwerk et al. 2015) as is the pinyon-juniper (PJ) habitat (Rondeau et al. 2017). Climate change is likely to increase drought severity and intensity which increases fire risk to the habitat. Floyd et al. (2004) state that the strong uptick in Mesa Verde fires since 1996 is outside the natural range of variation and likely due to a change in climate variables.

In 2002 the Long Mesa Fire burned 38% of the Mesa Verde National Park population (Anderson 2004), transforming the old-growth pinyon pine-juniper woodland into a grassland, currently comprised of native and non-native herbaceous species with scattered shrubs.

The fire occurred one year after permanent baseline transects were established to estimate the population of CMM. Post-fire management included a combination of seeding native grasses and spraying weeds, however some areas were never seeded or sprayed. The seed mix was comprised of three native bunch grasses (Indian rice grass, *Acnatherum hymenoides*, squirrel tail, *Elymus elymoides*, mutton grass, *Poa fendleriana*), and one rhizomatous grass, western wheatgrass (*Pascopyrum smithii*). Of these species, the western wheatgrass does not occur in old-growth PJ stands on Chapin Mesa. Mutton grass, a native bunch grass, is most common in unburned PJ habitat. The primary purpose in seeding was to eliminate invasive species, especially musk thistle (*Carduus nutans*), Canada thistle (*Cirsium arvense*), and cheatgrass (*Bromus tectorum*), the three species of greatest management concern and considered highly likely to increase after the 2002 Long Mesa fire (Floyd et al. 2006). Western wheatgrass averaged 26% cover in 2016 (range of 0-70%) and 19% in 2019 (range 0-38%).

Cheatgrass averaged 53% cover in 2015 (range of 12-76%) (Rondeau 2016) and 25% cover in 2019 (range 8-38%). These two species are considered very competitive and have been documented as changing the species composition and available soil moisture (e.g., Weaver 1942; Parkinson et al. 2013).

In 2011, Kuhn and Anderson (2012) set up a study design to determine if CMM was negatively impacted by seeding and spraying. The only significant difference they found was that there were fewer CMM plants in areas that had been seeded and sprayed vs seeded and unsprayed, but there was no difference in density between areas that were seeded or unseeded. They did not detect any difference in the noxious weed musk thistle between any treatment type as it was below 1% cover regardless of treatment type. The grass cover of native and non-native species in 2011 in the burned areas was 42%, vs 15% in unburned (Kuhn and Anderson 2012). In 2019 the grass cover of cheatgrass and western wheatgrass was at 45% (this report).

Managing rare plants such as Chapin Mesa milkvetch can prove difficult due to the lack of information regarding basic life history traits, population status, and population trends (Thompson 2004). Conducting a demographic analysis, i.e. the study of population size and the growth, survival, and reproduction of individuals within a population, is necessary to inform efficient recovery efforts for the species (Schemske et al. 1994). These studies are especially imperative for species proposed for listing under the Endangered Species Act. Chapin Mesa milkvetch is among the rarest of Colorado's endemic plant species. It is considered globally critically imperiled (G1) by the Colorado Natural Heritage Program (CNHP) and was declared a candidate for listing under the Endangered Species Act in 2010 (USFWS 2010). The purpose of our monitoring study is to provide Mesa Verde National Park with natural history and trend information that can inform their management decisions. In light of the high risk of the remaining old-growth PJ habitat experiencing a catastrophic fire, we set out to address the following questions, primarily related to the effect of the 2002 Long Mesa fire. The questions in gray font have not been addressed.

- Does fire kill Chapin Mesa milkvetch (CMM)?
- What weather variables correlate with the variation in annual emergence?
- What environmental variables are associated with the variation in density?
- To what degree does a burn event affect density of CMM over time?
- To what degree does a burn event affect flower and fruit production?
- To what degree does a burn event affect age class distribution, germination, and seedling survival?
- How often do seedling years occur and what are the climate variables associated with good seedling years?
- Do extreme droughts impact any or all age classes? Is the drought effect different in burned vs unburned area?
- How does post-fire conversion to a grassland change the vital rates over time?
- Is deep and shallow soil moisture altered by the conversion to a grassland?
- What is the average life span of CMM?
- Why does CMM have a limited distribution?
- What is the dispersal mechanism for seeds and what is the seed viability?
- Who are the primary pollinators and how do they vary across burned/unburned areas? What do the pollinators need?

- As post-fire succession marches forward, how does the shrub and grass composition change?
- Is there a difference in vital rates in areas that were seeded vs not-seeded after the fire?
- Is there a difference in shrub cover in areas that were seeded vs not-seeded after the fire?
- Can we provide restoration recommendations for future seeding following burns?
- How does soil type affect vital rates?
- Will succession in the burned area reverse the downward trend?

In order to answer these questions, we established a long-term monitoring project with permanent belt transects for measuring density and permanent demography plots to address vital rates. The original belt transects were established prior to the 2002 burn and provide the baseline information needed to answer density questions associated with fire effects.

From the above set of questions, we can only report on the first ten questions, however, we believe the other questions can be answered with additional time on the existing study as well as expanded data collection. As monitoring years continue, we intend to answer these other important questions that can help managers ensure the long-lasting viability of Chapin Mesa milkvetch.

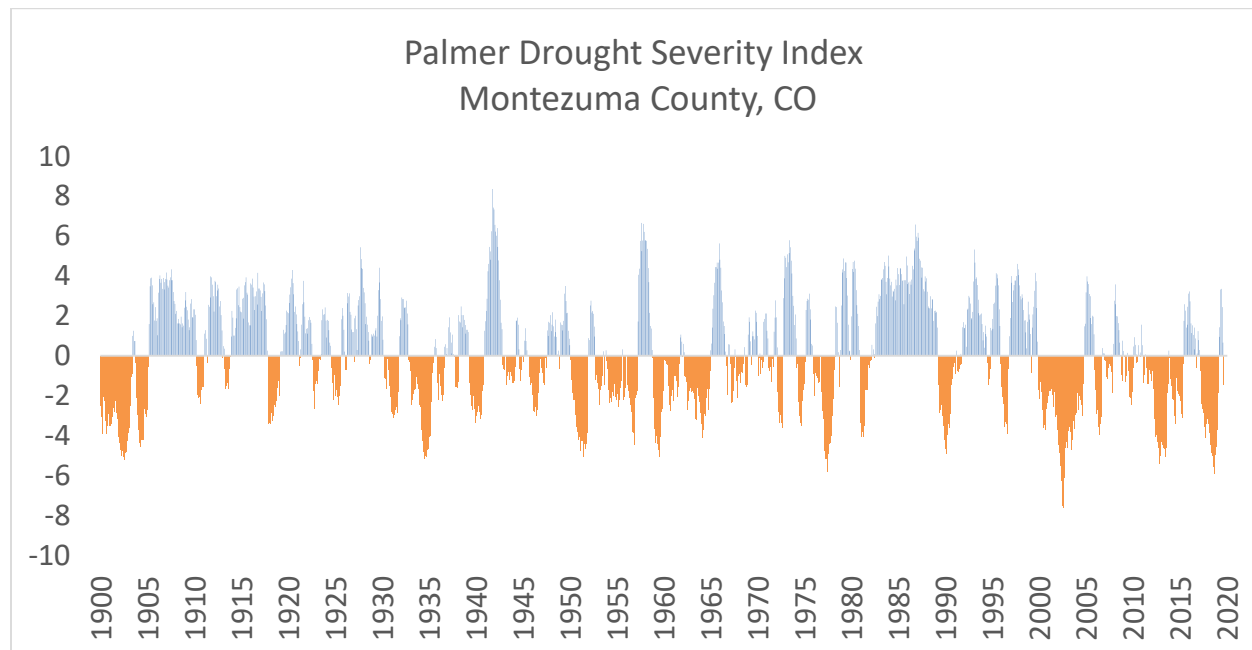
## Weather 2019

The winter of 2019 was considered very wet and cool, with  $-2^{\circ}\text{F}$  below average temperature and 87% above average precipitation compared to 1971-2000 (MEVE weather records). This was in sharp contrast to the extremely dry winter in 2018 (Figure 1). The 2018 drought finally broke in December 2018 (Figures 2 and 3). Figure 3 and Table 1 provide more details.

*Palmer Drought Severity Index.* The Palmer Drought Severity Index (PDSI) for Montezuma County (Abatzoglou et al. 2017; Figure 2), depicts wet and dry periods since 1900. Years with a PDSI above 0 detect wet years while years below 0 detect dry years. The severity is noted by the number on the y axis. The severe droughts of 2002 and 2018 were the most severe since 1900. While winter moisture is a determinant for Chapin Mesa milkvetch emergence, overall drought is a determinant for PJ habitat and its increased risk to mortality from fire or insects.



**Figure 1.** The winter precipitation of 2018 was 64% below the 1971-2000 average, while the winter of 2019 was 87% above average. The abundant winter moisture in 2019 meant that the deep soil moisture was replenished.



**Figure 2.** Palmer Drought Severity Index for Montezuma County, 1895-2019 (Abatzoglou et al. 2017). The blue bars represent wet years while the orange bars represent dry years.

Climate variables associated with different life stages. **Winter moisture** is critical for spring emergence. Emergence is high following winters with average-above average precipitation and low following a winter drought. **Spring shallow moisture** strongly influences seed germination. April and May are the prime germination months, and it appears that wet springs or rain events that saturate the topsoil, approximately a  $\geq 0.3''$  precipitation event, is important for seedling germination. The onset of flowering is probably associated with air and soil temperature. Flowering was early in 2015 compared to 2016; 2015 winter temperatures were 5°F warmer than 2016, whereas spring temperatures were very similar in both years. **Summer temperature and moisture** was thought to play a critical role for seedling survival (Rondeau 2019), however there was good seedling survival in 2019 despite the very dry summer and above average temperature, thus negating that assumption. Seedlings put most of their energy into growing a root system that can reach the deep soil moisture before fall dormancy. While summer precipitation helps replenish shallow soil moisture, due to abundant photosynthesis, plants utilize most of that moisture, thus deep soil moisture is not replenished by summer rain (see Figure 22 under soil moisture). **Fall moisture** may be the least important variable as CMM becomes dormant sometime during the fall. Table 2 summarizes the important climate variables by life stages.

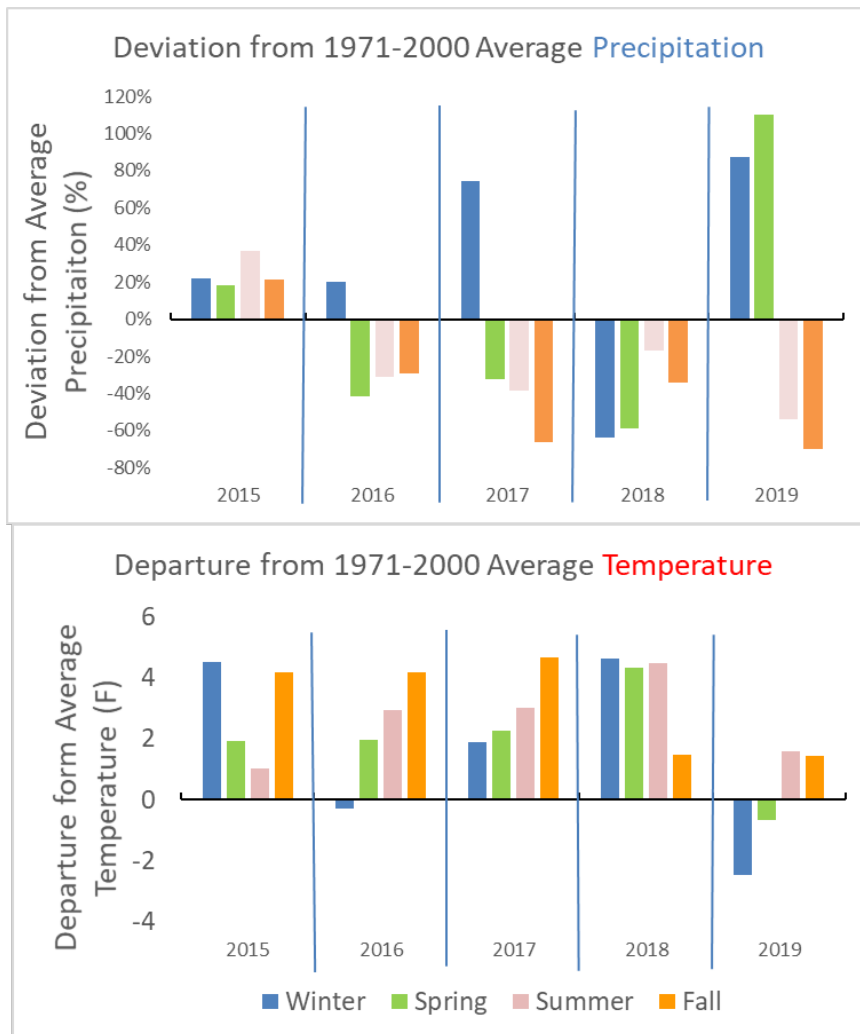


Figure 3. Chapin Mesa summary of 2015-2019 precipitation and temperature compared to 1971-2000 average (MEVE weather records). Temperatures for all years but 2019 were above average, with 2018 the warmest.

**Table 1. Summary of 2015-2019 winter and spring temperature and precipitation compared to 1971-2000 average (MEVE weather records).**

Year	Winter	May	Summer
2015	Hot and Wet	Cool and Wet	Average and Wet
2016	Average and Wet	Average and Wet	Hot and Dry
2017	Warm and Wet	Cool and Average	Hot and Dry
2018	Hot and Dry	Hot and Dry	Hot and Dry
2019	Cool and Wet	Cool and Wet	Warm and Dry

**Table 2. Seasonal climate variables as they relate to different life stages of Chapin Mesa milkvetch.**

Season	Life Stages	Favorable Conditions	Observed differences between Burned/Unburned	Notes
Winter (Dec-Feb)	All	≥ Average precipitation replenishes deep soil moisture	None	Winter precipitation strongly influences the number of plants that emerge the following spring; nearly zero emergence after severe winter droughts.
Spring (April-May)	Seedlings	Moist shallow soils are needed for germination. Multiple pathways, e.g., wet springs or multiple rain events in April/May	Fewer seedlings in burned vs unburned after 13 years post fire. Seedlings were abundant in burned areas for at least the first few years post fire	Seedlings require wet shallow soil for germination. Rapid root growth is necessary to tap into deep soil moisture.
Spring (March-May)	Timing of flowering/fruitleting	Unknown	Timing differences between burned/unburned have not been observed	We have low confidence on what climate variables correlate with flowering times.
Summer (June-Aug)	Seedlings and yearlings	Moist deep soils. Monsoons may not be critical to seedling survival based off of high seedling survival and low monsoons in 2019	Shallow soil temperatures were 5-7°F warmer in burned vs unburned	Root production is critical for surviving to the next year. Seedlings put most of their energy into growing deep roots; warmer shallow soils require more water. Competition with grass may inhibit seedling survival.
Fall (Sept-Nov)	All	Largely unknown as plant is dormant by late September-early October	None?	We are unclear what impacts the fall season has. The plant goes dormant around October and it may be that a dry fall can compound winter drought. Largely unknown

## METHODS

To establish density counts on Chapin Mesa within the National Park, we re-sampled the 2001 transects that were established one year prior to the Long Mesa fire (Figure 4) using the same methodology as Anderson (2001). A center line was established on the easting UTM, NAD83 and all plants were counted within a 5 m block from both sides of the center line. We separated out seedlings from immature and adult plants. Density was recorded as number of plants/m<sup>2</sup>. A total of 197 transects were sampled. Each transect was scored as being burned, unburned, or mixed. The mixed category included areas that had been mechanically thinned or included a mix of burned and unburned areas within a transect. Burned transects = 63; unburned = 105, and mixed = 29.

For density trend, we re-sampled a subset of the 2001 transects, N = 44, in years 2003 and 2011-19 (Figure 5). We compared annual plant density to the variation in seasonal precipitation data to assess any patterns associated with year-to-year variation.

Demography plots were established (Figure 5) to assess reproductive output and age class distribution (N = 22). Two of these demography plots were established in 2003 as 10 x 10 m plots; Sun Temple (burned in 2002) and Sun Point (unburned), both chosen for their high-density counts (Anderson 2004). The remaining 20 demography plots were established in 2015 as 50 x 2 m plots, 10 burned and 10 unburned. The demography plots that were established in 2015 are along the belt transect lines and represent the higher density transects; that is, they were not randomly selected but rather selected based on high number of individuals (Figure 5). All plants within the demography plots were classified into age classes: adult, immature, yearling, or seedling. We counted number of flowers, aborted flowers, fruits, stems, and height for each plant, in addition to percent browsed. We placed a 1 m<sup>2</sup> frame at permanently referenced positions at the beginning of each transect in order to mark and track selected individual plants over years. We have deemed these our “poker” plots, as we use different color poker chips to represent age classes for archival photo records. Additional transect photos are taken from the 0 and 50 m mark.

In addition to collecting CMM data, we collected hourly soil temperature data at a 10 cm depth (EL-USB-1 EasyLog sensor) and soil moisture data four times a day at 10 and 35 cm depths (Decagon 10HS moisture sensor with HOBO H21 data logger). Originally we had 6 soil temperature and moisture stations but in December 2017 we established an additional 6 stations, all adjacent to poker plots (Figure 20). Six of the stations are within the burned transects and six are within the unburned transects.

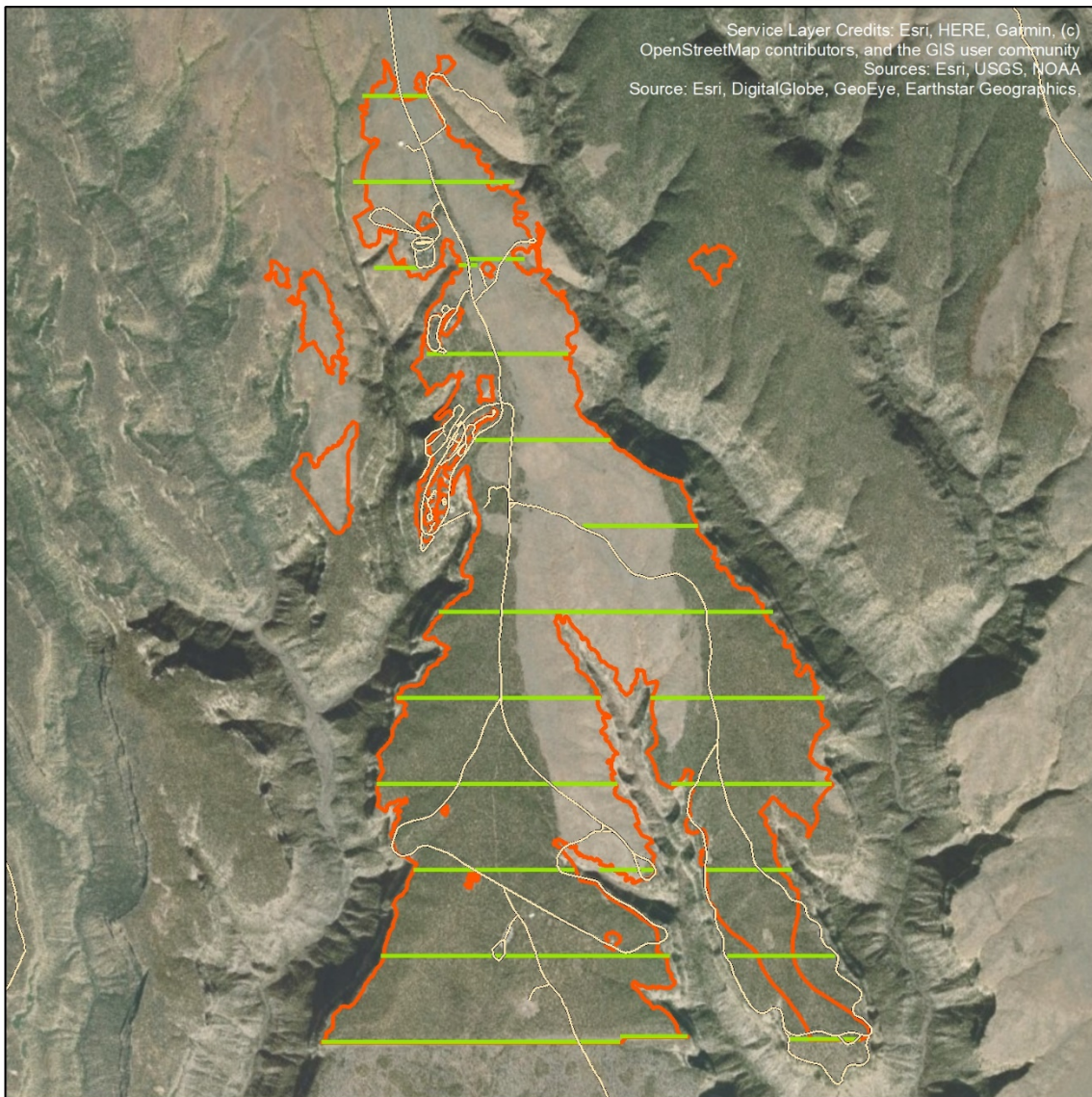
For each of the soil/temperature logger sites, we collected soil samples at the 10 and 35 cm depths. These were analyzed by Colorado State University Soil Lab (Appendix 3).

*Analysis.* Since annual density counts were strongly correlated with winter precipitation (Rondeau 2019), we estimated expected density based on the linear regression equation established from re-sampling all plant ages detected on 22 unburned transects in 2003 and 2011-2019. We compared the 2019 average density observed in burned and unburned transects (all age classes) separately with expected density. To determine if there was a significant difference between burned and unburned transects, we conducted Mann-Whitney U test for the immature/adults and seedling classes, as the data was not normally distributed.



We estimated variation in density of individuals across Chapin Mesa for two sets of data: 1) adult and immature plants, and 2) seedlings only. Mid-points for each of 197 belt transect segments were attributed with plant counts from 2001 and 2019 surveys. Count data were transformed using the natural log of total transect segment count plus 0.001, in order to produce a more normal distribution. Transect segment mid-point locations and transformed count values were then used as the input to the Kriging procedure in ArcGIS 10.4.1 (ESRI 2015). Kriging was performed with a 525 m search radius (belt transects were ~ 500 m apart) and a 1 m output cell size. The output rasters were clipped to the mapped population boundary on Chapin Mesa (Anderson 2001), and did not cover the populations of West Chapin Spur and Park Mesa, since no transect points from 2019 surveys were available in those areas.

To determine if there was a significant difference in density trend between burned and unburned transects, we calculated a linear regression slope for each belt transect for the contiguous years 2011-2019. We tested the slopes of burned vs unburned with a two sample t-test, with unequal variances. For summer shallow soil temperature we conducted a two sample t-test for differences in minimum and maximum temperatures in burned and unburned plots.



### Chapin Mesa Milkvetch (*Astragalus schmolliae*)

- 2001 and 2019 Transects
- Roads
- Population extent

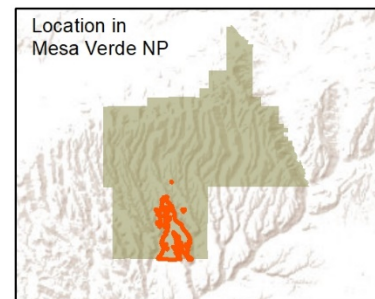
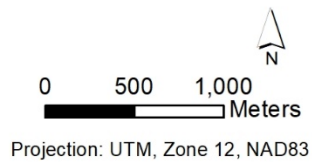


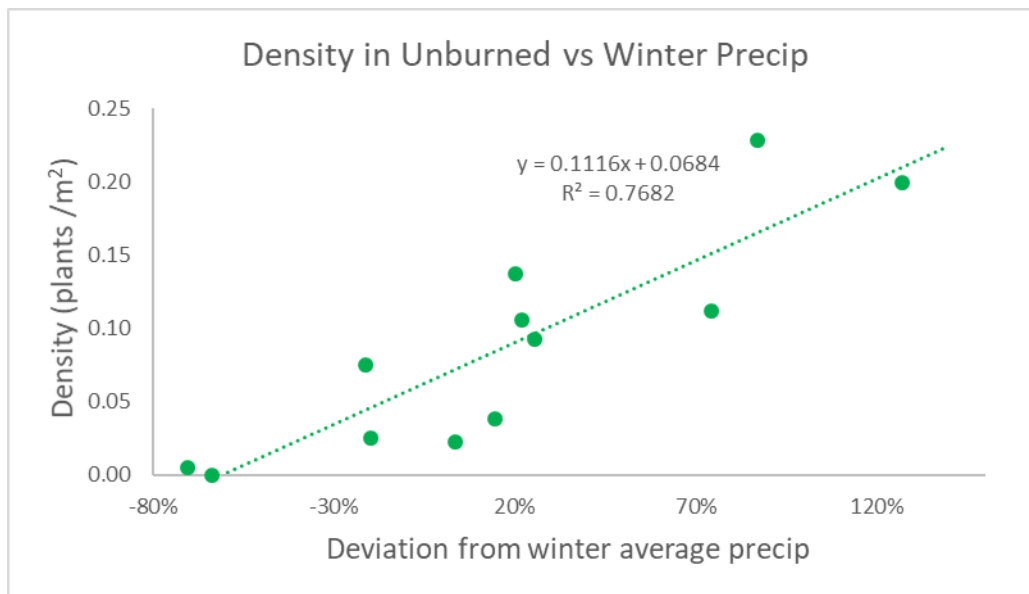
Figure 4. Transects sampled in 2001 and 2019 for Chapin Mesa milkvetch. Transects were 10 meters wide and 500 meters apart, and followed UTM northing lines.

**Figure 5. Location of repeat belt transects and demography plots. Blue lines represent belt transects; blue stars represent 2003 demography plots, and 2015-19 demography plots are denoted by numbers along blue lines (there are multiple plots associated with each number).**

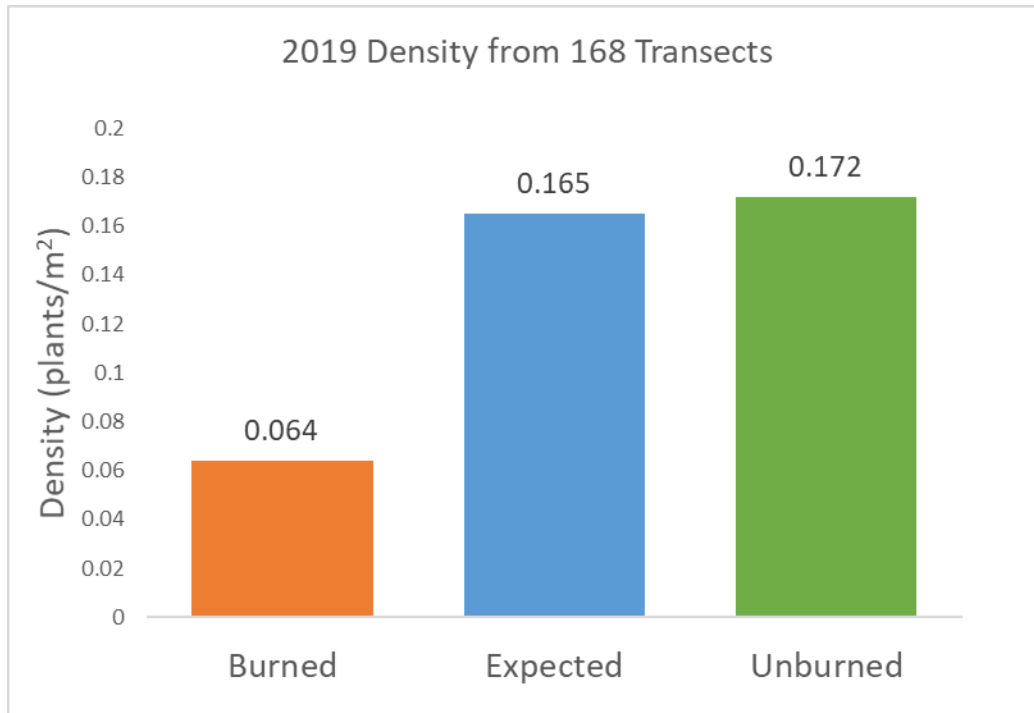
## RESULTS

### 2001 vs 2019 Density

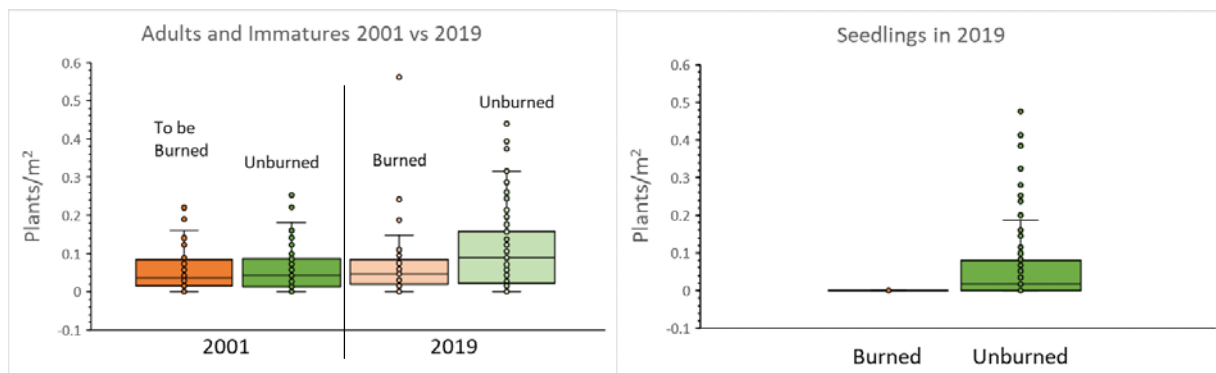
We used the linear regression equation from comparing plant density to the winter precipitation to establish expected average density (Figure 6). The winter of 2018-19 precipitation was 87% above the 1971-2000 average, thus the expected average density in spring 2019 was 0.165 plants/m<sup>2</sup>. The observed density in 2019 was 0.172 plants/m<sup>2</sup> in the unburned transects vs 0.064 plants/m<sup>2</sup> in burned transects (Figures 7 and 8). As noted in the captions, the burned transects had many fewer plants/m<sup>2</sup> than expected whereas the unburned transects were as expected. There was a striking difference in seedlings between unburned and burned. We counted 6079 seedlings in unburned transects vs 4 seedlings in burned transects (Figure 8). Mann-Whitney U-Tests, detected significant differences between burned and unburned transects ( $p < 0.008$  for immatures/adults and  $p < 0.001$  for seedlings).



**Figure 6. Chapin Mesa Milkvetch density (all age classes) versus winter precipitation. The precipitation values are from the Chapin Mesa weather station, and ranged from nearly 80% below average to 120% above average during the 12 sampling years (1980, 2001, 2003, 2011-2019). Winter precipitation is a good predictor of annual density counts ( $R^2 = 0.77$ ).**



**Figure 7. Chapin Mesa Milkvetch density (all age classes) in 2019. Expected values are from the linear regression equation that is shown in Figure 6. Burned transects (N=63) had 39% of the expected density while the unburned transects (N = 105) were nearly identical to expected density. The mixed transects were not included.**



**Figure 8. Box and whisker plots for Chapin Mesa milkvetch density. Adults and immatures in 2001 and 2019 in burned (or to-be-burned) and unburned transects (left graph). Seedlings in 2019 in burned and unburned (right graph). No seedlings germinated in 2001. There was no difference between groups in 2001, however by 2019 unburned transects (N = 105) had nearly twice the median density of adults and immatures than burned transects (N=63), 0.089 vs 0.046 ( $p < 0.008$ ). Seedlings were nearly absent from burned transects in 2019 vs a median of 0.018 seedlings/m<sup>2</sup> in unburned ( $p < 0.001$ ).**

Chapin Mesa milkvetch is unevenly distributed across Chapin Mesa. The pattern that was observed in 2019 was very similar to the pattern observed by Anderson (2001). The highest density areas were generally associated with areas nearest to the cliff edges and further south-downhill, whereas low density areas are on the mesa top and further north. The lack of plants on the southern boundary of the Cliff Palace Loop road is notable and may be worth more investigation. Figure 9 depicts the pattern

associated with immatures and adults, while Figure 10 depicts the pattern associated with seedlings. In general, the higher the density of immatures/adults the higher the seedling density. The notable exception to this is within the burned areas, where only 4 seedlings were counted.

**Figure 9. Mean local density of Chapin Mesa milkvetch throughout its range on Chapin Mesa, Mesa Verde National Park. Density was interpolated using 2019 belt transect data and clipped to the element occurrence boundary. In general, density increases near cliff edges (east-west gradient) and down (south) the cuesta.**

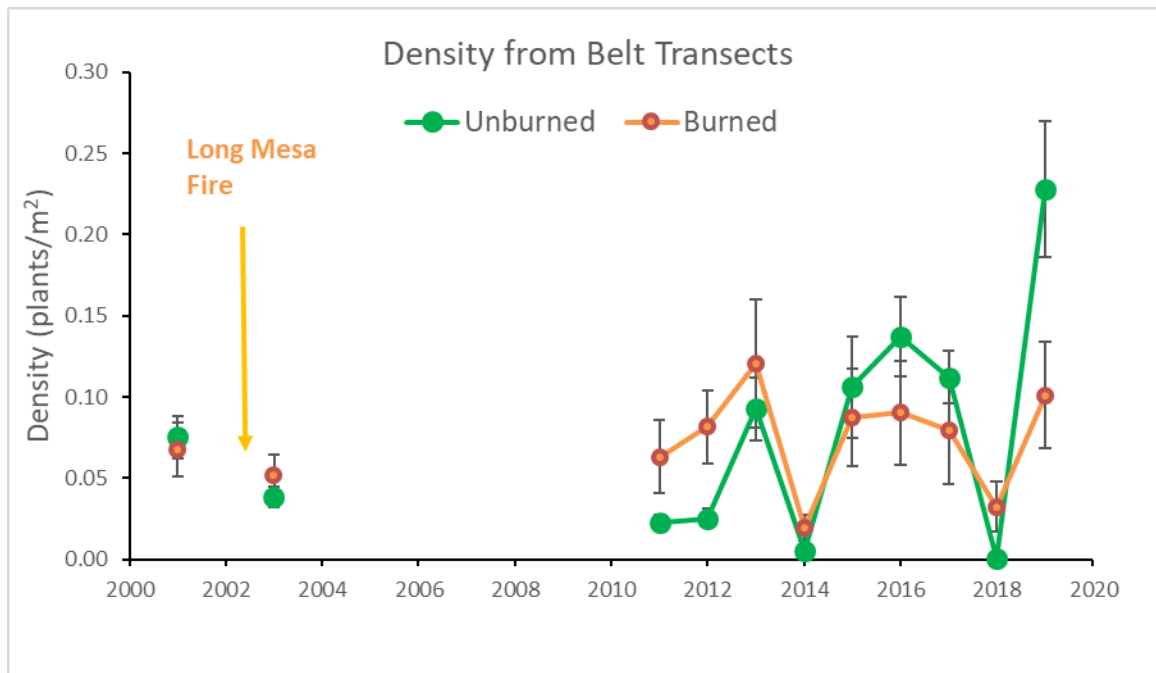
**Figure 10. Estimated Chapin Mesa milkvetch seedling density across Chapin Mesa. The 2002 Long Mesa fire (outlined in tan) had virtually no seedlings although immatures and adults were often present (previous map).**



### Density trend from repeated belt transects

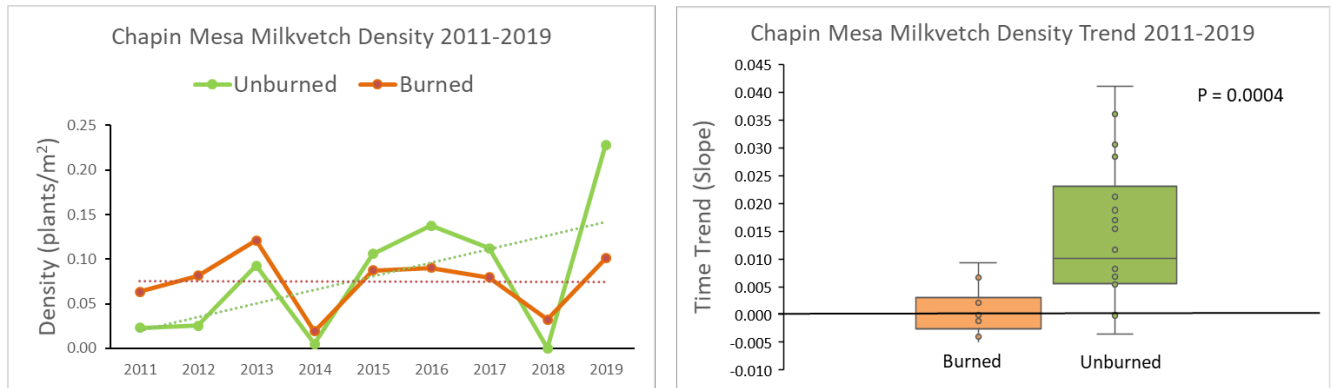
This was our eleventh year of measuring density from the permanent belt transects (N = 44). In 2019, we counted a total of 6429 plants, by far the highest count recorded, with the lowest of 420 and 519 plants observed in 2014 and 2018 respectively, two extreme winter drought years.

In 2001, prior to the 2002 Long Mesa Fire, CMM density was statistically indistinguishable between unburned and to-be-burned transects. Following the fire, relative density increased in the burned transects (significantly higher in 2011 and 2012), probably reflecting a nutritive or competitive benefit from the fire that benefitted recruitment. In 2013 the burn benefits were no longer statistically supported, though the burn area mean density continued to exceed that of the unburned plots. In 2014, another serious winter drought suppressed emergence and muted any persisting fire benefit. In 2015 the fire “benefit” had turned into a statistically insignificant liability. In 2017 the negative effects of the burn approached statistical significance and in 2019 the unburned transects had a much higher density than burned transects (Figure 11). The year-to-year variation in density is similar in burned and unburned transects (Figure 11) and was strongly correlated with winter precipitation (Rondeau 2019).



**Figure 11. Average density (plants/m<sup>2</sup>) for burned transects (N=17) and unburned transects (N=22) with SE bars  $\pm 1$ . After the 2002 Long Mesa fire and up until 2015, burned transects had higher density than the unburned transects, however by 2015 this trend reversed and the positive impacts from the fire are no longer evident.**

The density trend from 2011-2019 in unburned transects was positive, while it was flat in the unburned transects (Figure 12). The trend in plant density was significantly lower,  $p < 0.0004$ , in burned vs unburned (Figure 12), suggesting that burned areas currently have either a higher mortality or a lower recruitment (or both) compared to the unburned areas.

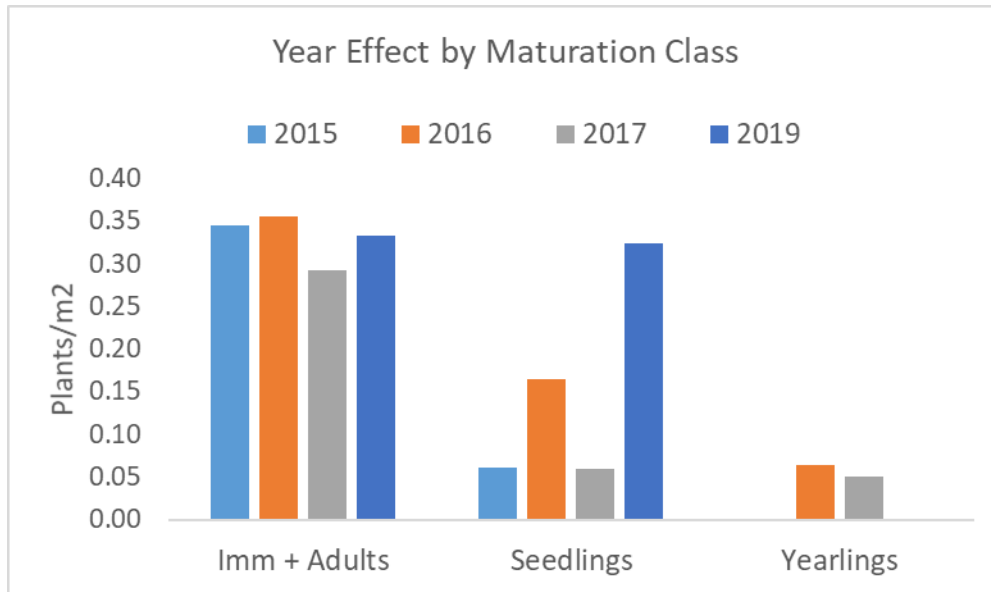


**Figure 12. Density trend of Chapin Mesa milkvetch from burned and unburned belt transects, 2011-2019. The dashed line represents the linear regression slope, with a positive slope for unburned transects, N=22, and no slope for burned transects, N=17. The box and whisker plots depict the trend (slope) for burned and unburned transects, which were significantly different ( $p=0.0004$ ). If this trend continues, the slope within the burned transects will become negative.**

### Density from demography plots

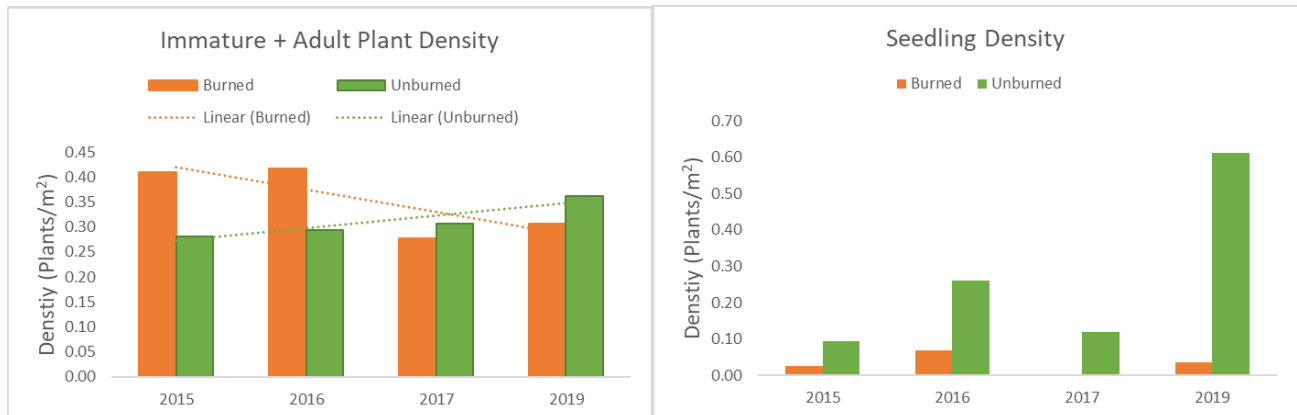
The overall population assessment is best determined from the repeat of the 2001 transects as these transects traverse the entire Chapin Mesa population within the National Park. The population trend is best assessed from the repeated belt transects, a subset of the 2001 transects (above). The demography plots can help us determine trends in age class distribution, specifically detecting recruitment (seedlings) and mortality of immatures and adults. The demography plots were purposely chosen from known high density areas, therefore they are good at detecting changes in high density areas, which may not reflect trends in the lower density areas.

The wet winter and spring of 2019 was a perfect combination for both emergence of immatures and adults as well as seed germination. We counted over 350 seedlings, the highest count of 2015-19 years (Figure 13). The adults were robust with numerous stems and abundant flowers (see cover photo and Appendix 6 for additional photos). The only unusual aspect of 2019 was that the fruit count was not much higher than 2016 (**Appendix 1**) and likely due to the cold and wet spring (Figure 3) that might have affected pollinators. In addition, the 2018 drought may have negatively impacted the pollinators. With that said, fruits were still abundant on some plants.



**Figure 13. Total number of plants within each maturation class by year, 2015-2019 (excluding 2018, due to extreme winter drought). Burn and unburned transects were combined. N=22 for each year. There was no difference in immature and adult plants between years, however 2019 was a much better year for seedlings and there were no yearlings in 2019 due to the kill from the 2018 drought. The high seedling count in 2019 was most likely due to the wet spring.**

*Burn Effect.* The difference between burned and unburned continues to widen with each passing year. Due to mortality of immatures and adults and lack of recruitment, the overall population in the burned plots is declining. In 2015, immatures and adults had a 46% higher density in burned vs unburned plots, but by 2017 there was no statistical difference and by 2019 the gap had widened (Figure 14). Between years 2015-19, there was a 24% loss in the burned plots, while there was a 28% increase in unburned plots (Figure 14). This same pattern was also evident with the marked individuals within the poker plots (see poker plot summary). The difference in seedling density was even more pronounced with nine times lower density in burned vs unburned plots. The average density from 2015-2019 was 0.03 seedlings/m<sup>2</sup> vs 0.27 in unburned (Figure 14 and 15). Yearlings were also skewed, with four times lower density in burned plots vs unburned. See Appendix 1 and 2 for demography plot data from 2015-2019.

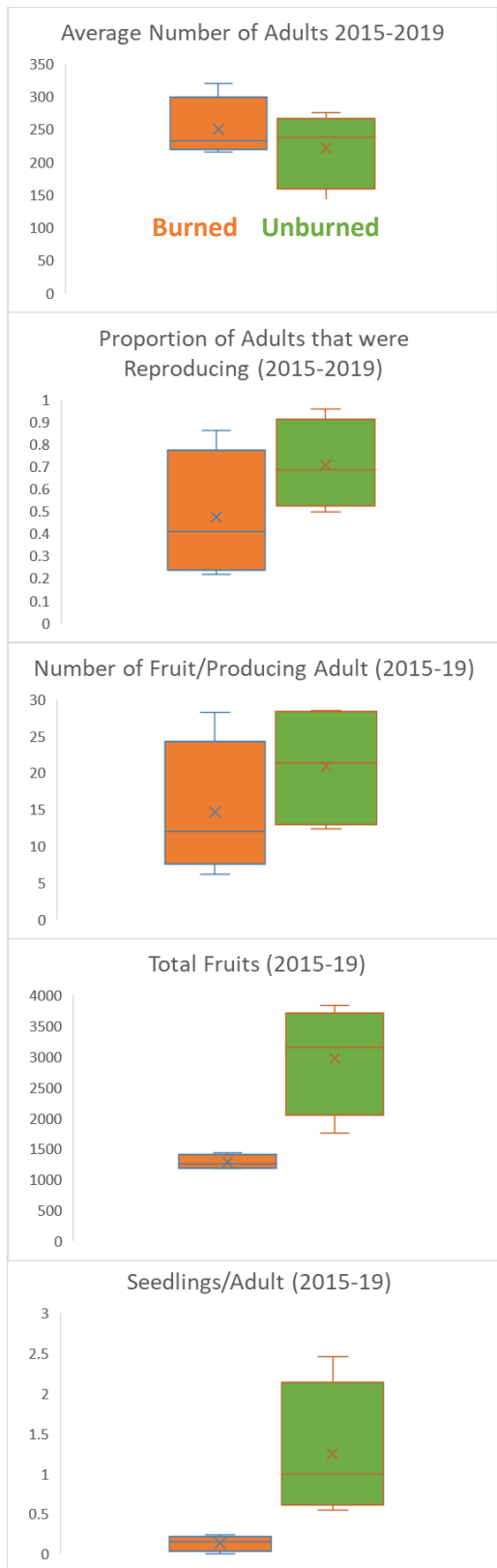


**Figure 14. Average density of immatures/adults and seedlings in burned (N=11) and unburned (N=11) demography plots, 2015-19 (note that 2018 is not shown as most plants did not emerge due to extreme winter drought). There was a 24% loss in density of immatures and adults in the burned plots, while there was a 28% increase in unburned plots. Seedling density remained low in burned plots, regardless of year, whereas we observed strong annual variation in seedlings within unburned plots.**

#### **Reproductive output, 2015-2019**

The best metrics for reproductive output are 1) the proportion of adults that were reproducing, 2) the number of fruits/producing adult, 3) the total number of fruits, and 4) the number of seedlings/adult. A burn effect compares the burned areas to unburned areas. See Figure 15 for the results listed below.

*Burn Effect.* The median number of adults was similar between burned and unburned plots when all years (2015-19) were lumped; thus if all things were equal, reproductive output should be the same for burned vs unburned, however we know that there was high mortality of adults in burned plots. The proportion of adults that were reproducing (flowering or fruiting) was nearly twice as high in unburned vs burned plots (median was 0.7 vs 0.4, respectively). The median number of fruits/producing adult was nearly twice as high in unburned vs. burned plots (an average of 21 fruits/producing adult vs 12, respectively). This led to slightly more than two and half times as many fruit produced from 2015-19 in unburned (3143) than burned (1259). Given that the total number of fruits in burned plots was significantly lower than unburned, it means that the seed bank would be lower. The combination of a lower seed bank, coupled with high grass cover, may be a reason why we observed fewer seedlings in burned areas. There were five times more seedlings/adult in unburned vs burned plots (median was 1.0 vs 0.2, respectively).



Total number of adults was not significantly different between burned and unburned, however we have observed higher mortality of adults in burned vs unburned.

The proportion of adults that were reproducing was nearly twice as high in unburned vs burned (median was 0.7 vs 0.4, respectively).

The median number of fruits/producing adult was nearly twice as high in unburned vs burned (21 vs 12, respectively).

The median fruit production was 2.5 times higher in unburned vs burned (3143 vs 1259). There may be at least two issues: 1) fewer flowers and 2) fewer pollinators in the burned.

There were 5 times more seedlings/adult in unburned vs burned (median: 1.0 vs 0.2) Total seedling counts (not shown) were 10 times higher in unburned vs burned (299 vs 29, respectively). Given that the total number of fruits in burned plots was significantly lower than unburned, it means that the seed bank may also be lower. The combination of a lower seed bank, coupled with high grass cover resulting in lower soil moisture, may be a reason why we observed fewer seedlings in burned areas. This was not the case prior to around 2013.

**Figure 15. Burn effect on adults and reproductive effort from 11 burned and 11 unburned demography plots.**

### **Survival by age class of marked plants (poker plots)**

Our 1m<sup>2</sup> “poker” plots allow us to follow marked individuals from year to year. Of special interest is how each age class fared over the sampling years, i.e., what percentage of the individuals survived to the next year, or in the case of seedlings and yearlings, what percentage survived and entered a new age class. We compared burned plots to unburned plots. In total, we have marked 267 individuals, 69 in the burned plots and 198 in the unburned plots. In addition, we have observed that on rare occasions some immatures and adults can be dormant for two consecutive years.

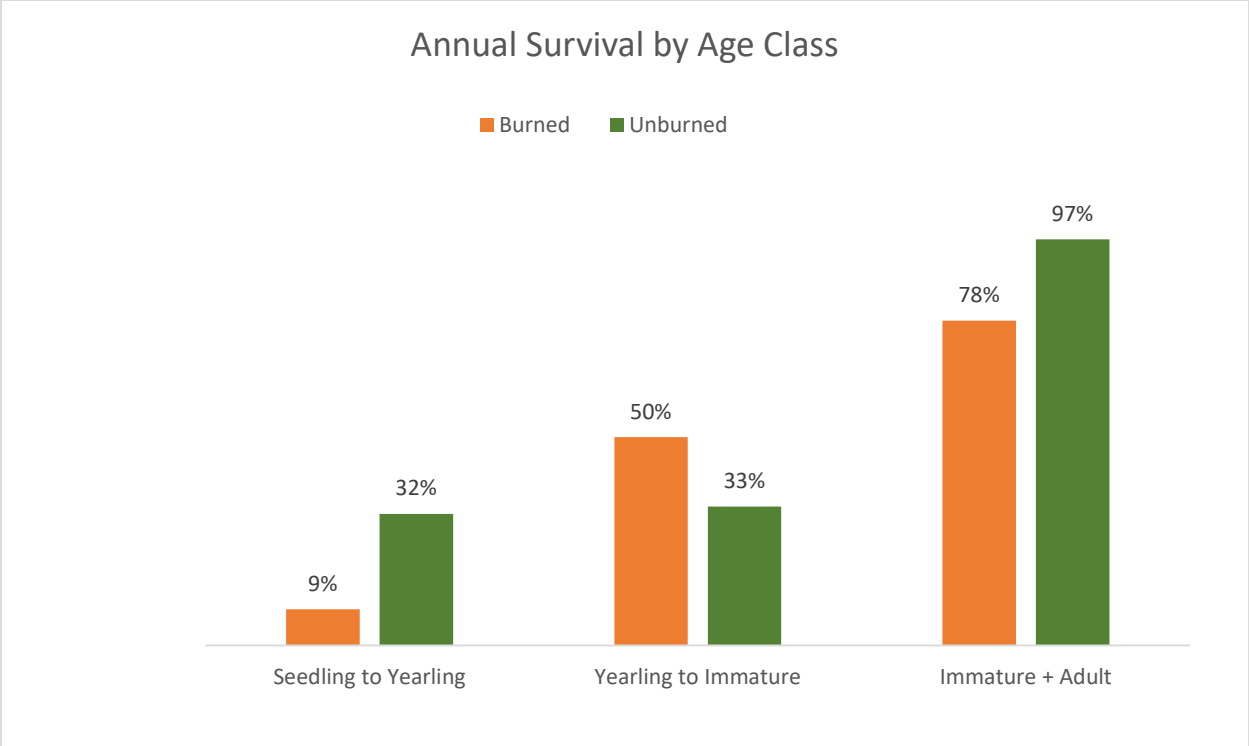
In the 2018 extreme drought year, the only poker plots with plants were 77-5, 77-6, and 78-1, all burned plots, with one, one, and 5 plants, respectively. No flowers or fruits were observed on any of those plants in 2018.

The following information is for 2015-2019 and does not include 2018.

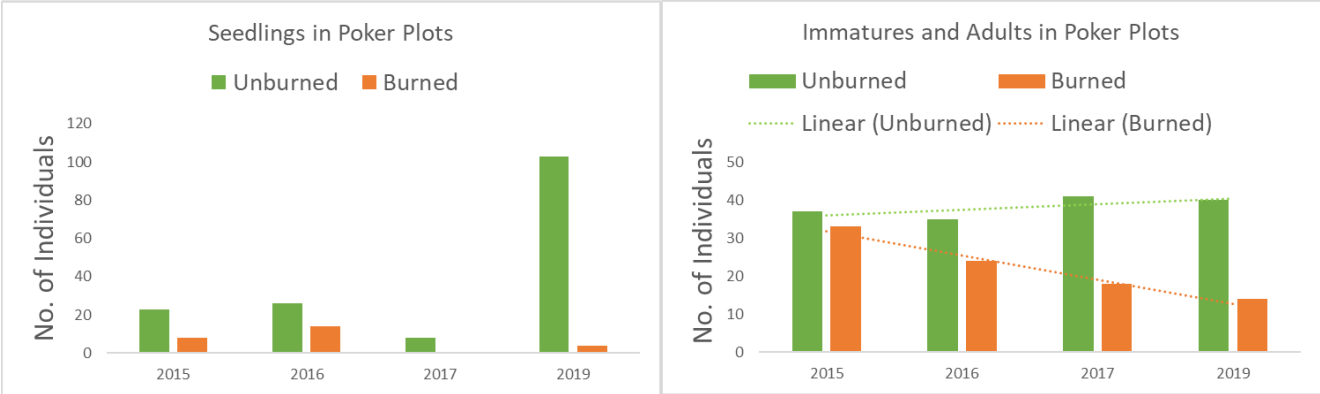
*Seedlings and Yearlings.* We marked 186 seedlings, 26 in the burned plots and 160 in the unburned plots (Figure 17). Not counting 2019 seedlings since we will not know the fate of them until 2020, only 2 of the 22 seedlings (9%) in the burned plots survived one year, while 18 of the 57 seedlings (32%) survived in the unburned plots (Figure 16). Once the plant became a yearling, the chances of surviving another year improved. One of the two yearlings (50%) became an immature in the burned plots, while six of the 18 yearlings (33%) became immatures in the unburned plots (Figure 16). The survival rate of seedlings to immatures was 5% in burned (1 plant) and 12% in unburned (6 plants). The 2015 seedling cohort was the only year that was able to survive the 2018 drought, i.e., any plant that was a seedling or a yearling going into the 2018 drought perished, thus the plant had to be at least 3 years old (immature) to survive the extreme drought year of 2018.

*Seedling survival within the 2019 summer.* In spite of the summer drought (50% below average precipitation – Figure 3), seedling survival was high. Of the 94 seedlings tagged in May, 60 were still alive at the end of August. This information may negate our original hypothesis that monsoons are important to seedlings. It may be that seedlings put all of their energy into growing deep roots and by July and August they are tapping into deep soil moisture rather than shallow soil moisture. Shallow soil moisture is critical for seed germination, however by July, and possibly June, the roots have grown into the deeper soils. It may be that monsoons could still be important during other years, but in wet winters/springs such as 2019, the monsoons were not critical to seedling survival. See Rondeau (2017) for additional information on seedlings surviving the summer months.

*Immatures and Adults.* We marked 80 immatures and adults, 38 in the burned plots and 42 in the unburned plots. The annual survival rate in burned plots was 78%, while 97% of the plants survived in the unburned plots (Figures 16 and 17). We believe pocket gophers are one of the main causes of death in the burned plots.



**Figure 16. Annual survival by age class, 2015-19. Burned areas produced fewer seedlings than unburned, 23 vs 57, respectively (not including 2019). Only 9% of the seedlings made it to the yearling stage, while 32% made it in the unburned. One of the two yearlings in the burned plots became an immature, while 6 yearlings (33%) became immatures in the unburned plots. In addition to poor recruitment in the burned plots, the mortality of immatures and adults was higher than unburned. Basically there was a 22% loss/year of immatures and adults in the burned plots while unburned plots had a 3% loss.**

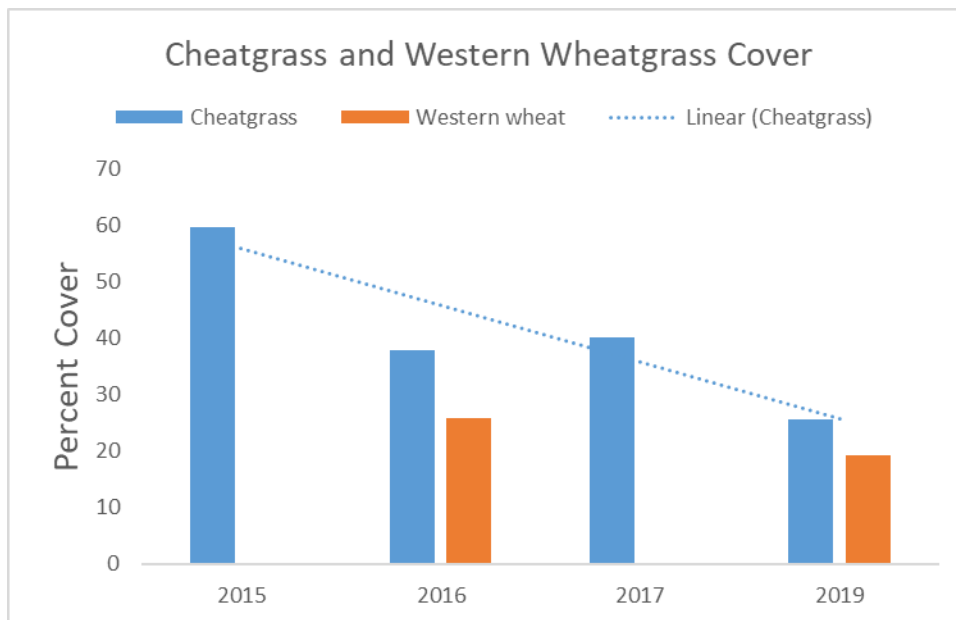


**Figure 17. Seedlings and immatures/adults in poker plots trend. Seedlings were more abundant in unburned plots vs burned (left graph). Immatures and adults in burned poker plots are dying and not being replaced, while there is a slight upward trend in unburned plots. Between the lack of recruitment (seedlings) and the high mortality of immatures and adults, the Chapin Mesa Milkvetch population in the burned areas are declining rapidly. This trend was also evident, however less drastic, for the demography plots (see Figure 14).**

### Cheatgrass, western wheatgrass, and browsing, 2015-2019

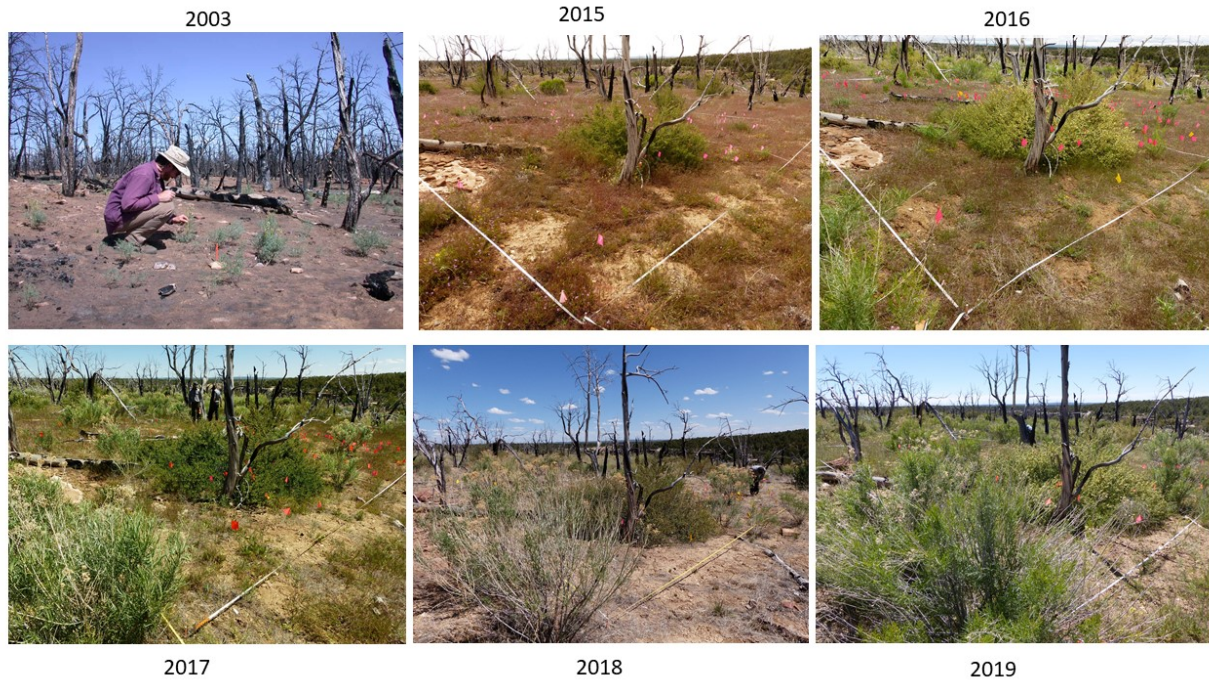
Cheatgrass, a non-native species, is one of the many species that have been favored by burning (Floyd, et al. 2006). We used cheatgrass as the primary surrogate for grass cover since it was the dominant grass in most burned plots (Figure 14), however it is important to note that western wheatgrass and smooth brome are also dominant in some of the burned areas, but are not present in the unburned area. Western wheatgrass was seeded after the burn, and while it is native to MEVE, it naturally resides in the valley bottoms, rather than the mesa tops. We have never encountered a single stem of western wheatgrass in the unburned plots. Western wheatgrass and smooth brome are very aggressive rhizomatous grasses. Western wheatgrass cover averaged 26% in 2016 and 19% in 2019 (we did not collect smooth brome cover). We measured cheatgrass cover at all of the demography plots in 2015-19. The peak of cheatgrass cover was in 2015, with 60% average cover (Figure 18). Live cheatgrass was basically non-existent in 2018, due to the extreme drought. From our dataset, it appears that grass cover has been declining steadily since 2015, however there was still a total of 45% cover of cheatgrass and western wheatgrass in 2019 (Figure 18). Kuhn and Anderson (2012) measured an average cover of 28% cover of cheatgrass and western wheatgrass in 2011. They also measured 15% cover of grass in the unburned plots. As seedling emergence was still significantly lower in burned vs unburned plots in 2019, it appears that even a 45% cover of grasses may still be too high for CMM seedlings. Figure 19 provides photographic representation of changes in the grass and shrub component within a burned plot.

Grass cover, especially cheatgrass and rhizomatous grasses, may be inhibiting seedling emergence and survival by competing for valuable soil moisture during the critical seedling germination months (April and May).



**Figure 18. Cheatgrass and western wheatgrass cover in burned demography plots from 2015-19 (N=11). While there is a notable downward trend, probably linked to shrub cover going up, the overall grass cover of 45% in 2019 was probably still too high as few Chapin Mesa milkvetch seedlings emerged. The grass cover in unburned plots averaged around 15% (Kuhn and Anderson 2012).**





**Figure 19. Sun Temple demography plot in 2003, one year after the fire, and 2015-2019. Grass cover was virtually nonexistent in 2003 and averaged 70% in burned areas by 2016. Competition for shallow soil moisture goes up as grass cover increases. By 2019, shrubs were reducing the cheatgrass, however fewer seedlings emerged than in the paired Sun Point plot.**

The structure of the vegetation is very different in burned vs unburned areas and therefore herbivory is likely to be different. We observed that horses, deer, and pocket gophers are more prevalent in burned areas than unburned areas, while cottontails appear to be abundant in both habitats. In 2016-19, we collected browse data. We did not find any difference in browsing between burned and unburned areas (ranging from an average of 1.5% to 4.5%). It is important to note that we cannot measure pocket gopher "browsing," as these animals eat the plant from below, normally destroying the entire plant. Our repeat photography in the poker plots strongly suggests that pocket gophers eat, and thus kill, Chapin Mesa milkvetch and that they may be at the root of the high immature and adult mortality rate in burned plots.

### **Soil Attributes and Temperature**

We established soil temperature and moisture sensors at 12 sites (6 burned and 6 unburned) (Figure 20); a deep soil moisture sensor was placed at a 35 cm depth and a shallow moisture sensor at a 10 cm depth to measure the periodicity of soil moisture. Temperature was collected at the 10 cm depth.

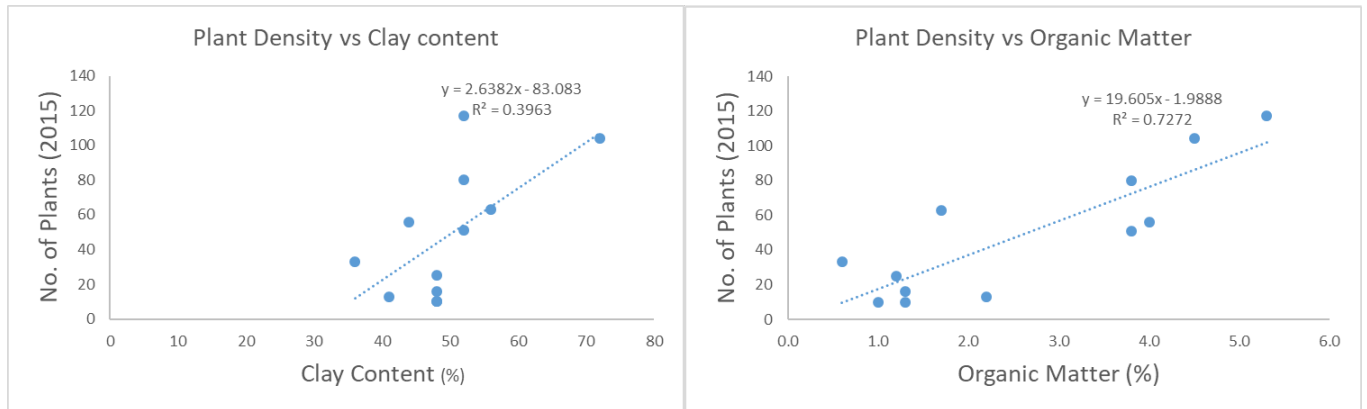
**Figure 20. Location of soil moisture sensors installed on Chapin Mesa milkvetch demography plots.**

### Soil texture and organic matter

We had Colorado State University analyze 10 and 35 cm depth soil samples for each data logging station (see Appendix 3 for CSU soil analysis results). There was no discernable difference in texture between burned and unburned sites, as all but one of the 24 samples were typed as clay. We analyzed the 35 cm depths to assess correlations between clay content and organic matter and plant density. The clay content ranged from 36-72% and the organic matter ranged from 0.6 to 5.3% (Table 3). In general, the higher the clay content the higher the plant density ( $R^2 = 0.4$ ) and organic matter had even a stronger correlation ( $R^2 = 0.7$ ; Figure 21) The combination of organic matter coupled with clay content was a good predictor of density, with the highest densities having both high organic matter and clay content ( $p = 0.001$ ;  $R^2$  adjusted = 0.72). As you move towards the cliff edge, the organic matter and clay content generally goes up (Table 3).

**Table 3. Organic matter, OM, (sorted from low to high), clay content (%), position on Chapin Mesa (top vs cliff edge), Chapin Mesa milkvetch density from 2015 (green denotes unburned and orange denotes burned). Organic matter (OM) and clay content are characterized as low, medium or high. Cliff edges have higher organic matter than the top of the mesa and generally clay content also goes up near the cliff edges. The combination of high organic matter and clay content is correlated with high Chapin Mesa milkvetch density.**

Plot	OM	Clay	Position	Density	OM	Clay
104-4D 35cm	0.6	36	Top	33	low	low
73-4D 35cm	1.0	48	Top	10	low	low
83-3d 35cm	1.2	48	Top	25	low	low
77-4D 35cm	1.3	48	Top	16	low	low
102-8D 35cm	1.3	48	Top	10	low	low
78-3D 35cm	1.7	56	Top	63	low	med
102-3D 35cm	2.2	41	Top	13	med	low
sun point 35cm	3.8	52	Cliff	80	med	med
78-1D 35cm	3.8	52	Cliff	51	med	med
104-3D 35cm	4.0	44	Top	56	med	low
73-1D 35cm	4.5	72	Cliff	104	high	high
77-6D 35cm	5.3	52	Cliff	117	high	med

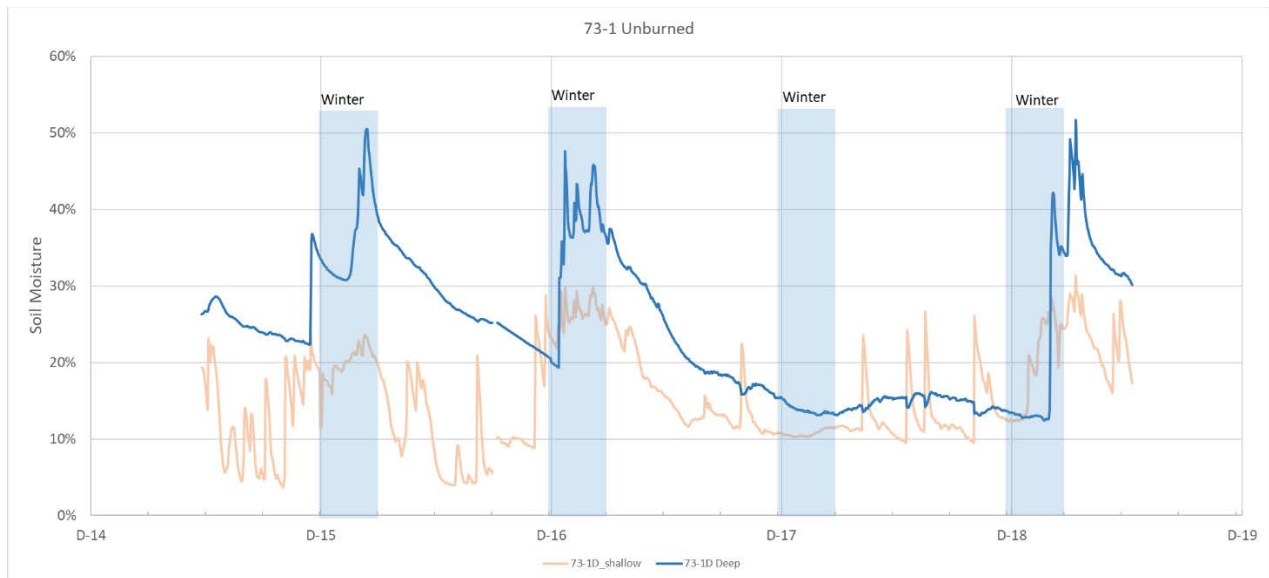


**Figure 21. Plant density as it relates to clay and organic matter from the 35 cm depth (N = 12). In general, the higher the clay and organic matter the higher the plant density. The strongest relationship was coupling organic matter with clay content. There was a strong correlation from a multiple regression analysis ( $p = 0.001$ ;  $R^2$  adjusted = 0.73).**

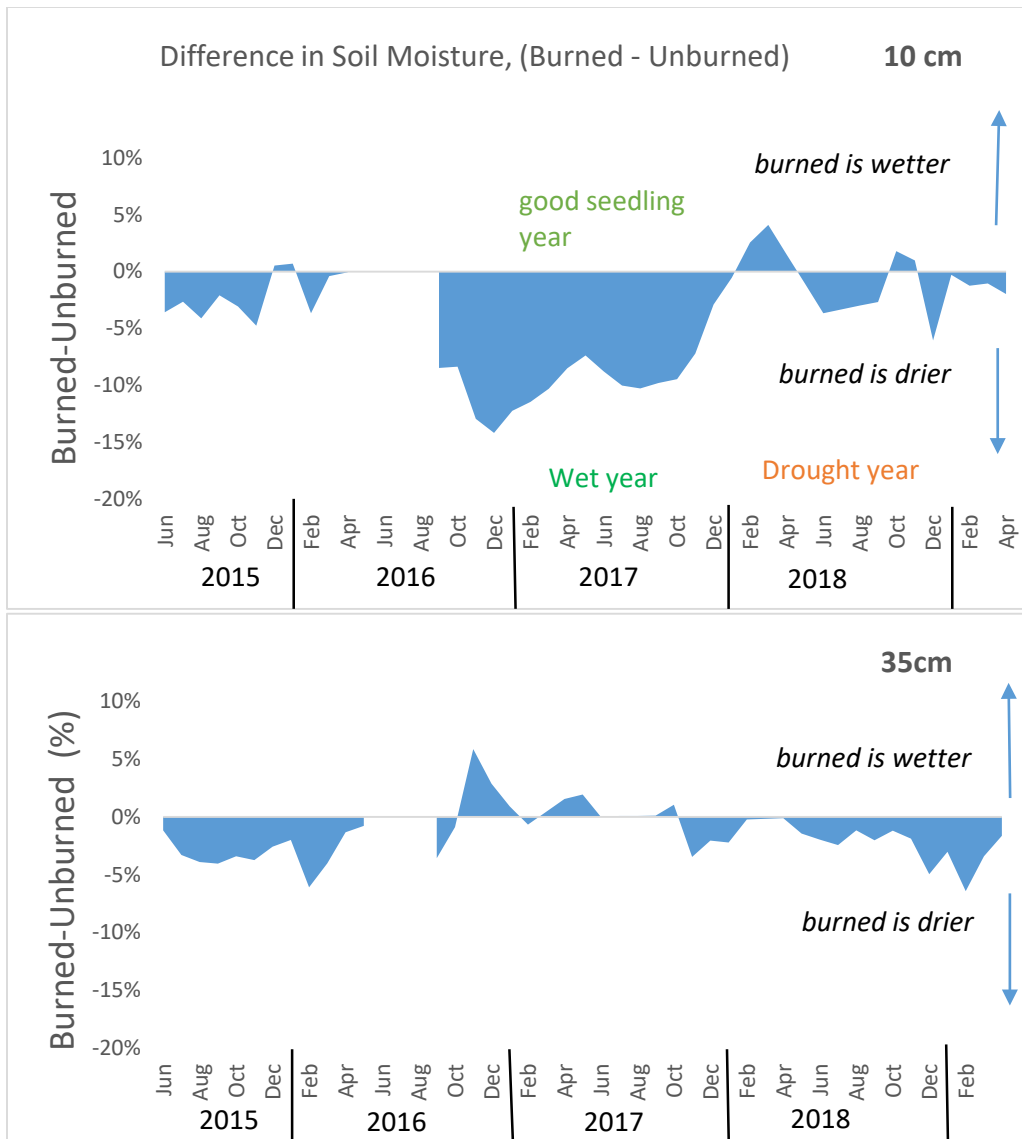
### Soil moisture

The original placement design for the soil moisture sensors had an equal sample size in burned and unburned plots, 3 plots each, however due to logger or sensor failures, we had numerous issues with collecting an adequate sample size. In December of 2017 we added an additional 6 sensors, evenly split between burned and unburned plots (Figure 20). To adequately compare soil moisture data it was necessary to calibrate the sensors, using Onset directions. The equations from the calibrations were used to adjust the output. We hypothesized that burned plots would have significantly drier shallow soils during the germination season (April and May).

While we only have three years of wet winter data, we observed an annual cycle in deep soil moisture at the 35 cm depth. Peak saturation occurred in mid-late February or early March (2019) and then steadily dried out until late fall (Figure 22). The monsoon rains never replenished deep soil moisture (Figure 22). For both deep and shallow soil moisture, we observed that burned areas are drier than unburned, with a larger difference in the shallow depths, which may help explain the lack of seedlings (Figure 23).

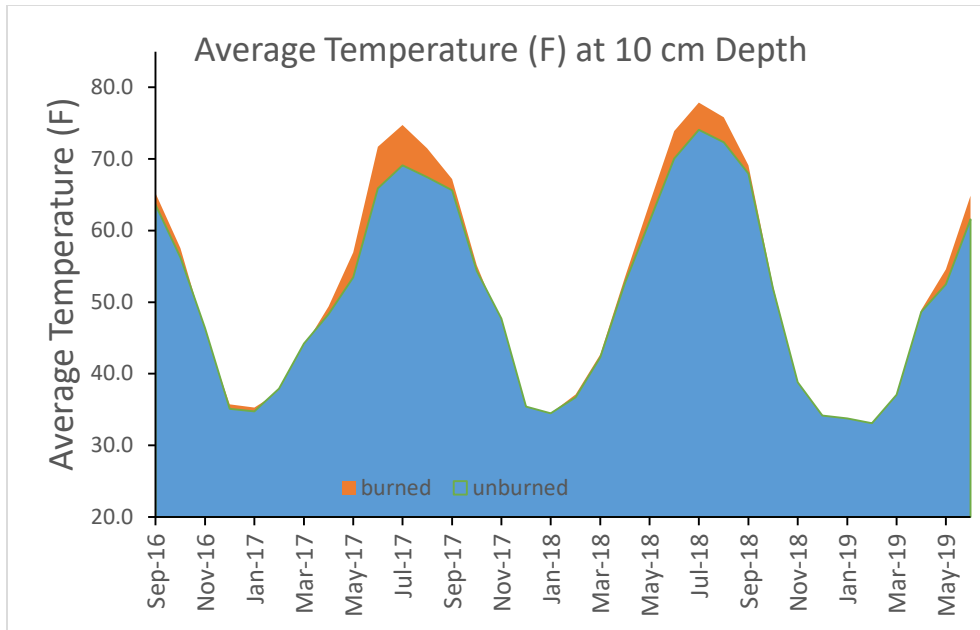


**Figure 22. Soil moisture from 73-1 at shallow (5 - 10 cm- orange line) and deep (35 cm- blue line) depths. Saturated soil moisture is around 50%, while complete dryness is around 0-5%. Deep soil moisture at all sites peaked in late winter (mid Feb to early March) and steadily declined until the following winter, that is, monsoon rains did not replenish deep soil moisture. The 2018 drought started in 2017 and did not rebound until February 2019. See Appendix 5 for all sensors.**



**Figure 23. Difference between average burned and unburned plots in soil moisture (burned-unburned) for 10 cm depth (top) and 35 cm depth (bottom). Zero percent indicates no difference between the average burned and unburned plots at that time. For example, if burned soil moisture was 35% and unburned was 50%, burned soil moisture was 15% drier than unburned soil moisture (shown as a negative on the graph). The soil moisture difference between burned vs unburned was greatest and most often negative at the shallow depth and only slightly different, and inconsistently different, at the deep depth. Burned shallow soil moisture was 10-15% lower than unburned, especially during the wet cycle of 2016-17. During the 2018 extreme drought, the difference was slight and inconsistent in direction. The shallow soil moisture, especially in April and May, is critical for seedling germination while deep soil moisture is critical for survival of all age classes. Thus based on deep soil moisture levels, we should not expect large differences between burned and unburned plots in the survival of immatures and adults. The burned plots are generally drier especially in the shallow soils, thus this could explain the lack of seed germination in the burned areas.**





**Figure 24. Temperature in burned and unburned plots. Temperatures are similar in burned and unburned except during the summer season, when burned becomes 3-5 F warmer. The 2018 drought was warmer than 2017.**

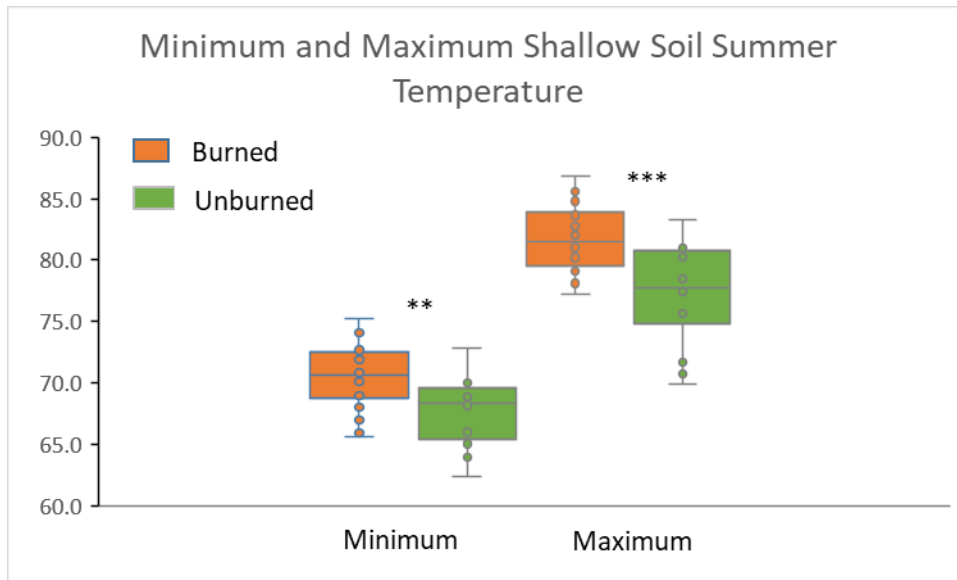
### Shallow soil temperature

*Method:* To capture information associated with seedlings, and their need for moist shallow soils, we placed temperature sensors at a 10 cm depth at 6 burned and 6 unburned demography plots (Appendix 4). Temperature is tightly associated with evapotranspiration, i.e., higher growing season temperatures equate to higher evapotranspiration and reduced soil moisture. Hourly temperature readings were summarized into daily minimum, maximum, and average. Seasonal averages were tabulated using the monthly averages (Figure 24).

*Results:* The primary significant difference in shallow soil temperature between burned and unburned plots occurred during the summer season (Figures 24 and 25). In 2018, the minimum temperature in burned plots averaged nearly 3<sup>o</sup> F warmer than unburned plots, while the maximum temperature was nearly 5<sup>o</sup> F warmer (Figure 25). These differences are most likely due to stronger radiation in the burned areas, due to the lack of shade from trees. The lack of trees does not appear to be as critical during the winter and fall months.

Late spring temperature (May) was also warmer by 2<sup>o</sup> F in burned vs unburned plots (min = 59<sup>o</sup> F vs 57<sup>o</sup> and max = 69<sup>o</sup> vs 67<sup>o</sup>, respectively).





**Figure 25. Minimum and maximum shallow soil summer temperature for burned (6) and unburned (6) plots, 2018. Summer months are June-August. Minimum temperatures were an average of 3<sup>o</sup> F warmer in burned plots while maximum temperatures were nearly 5<sup>o</sup> F warmer in burned vs unburned. A two-sample t-test was significant for both minimum and maximum temperatures between burned and unburned plots.**

## DISCUSSION

### 2018 Drought

The 2018 drought began to appear in March 2017 (Figures 2 and 3) however it was not officially considered a drought until October 2017. Starting in October 2017, the Palmer Drought Severity Index was deemed moderate and moved into the extreme category by December 2017, and it remained extreme as of the end of November 2018. In total, the monthly precipitation for nearly 21 months was below average. <https://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers/psi/201703-201811>. The 2002 and 2018 droughts were the most severe droughts since 1900 (Figure 2).

Impacts from the drought were not only evident in the Chapin Mesa milkvetch, but other species as well. The drought was expressed differently in burned and unburned areas. Shrubs were green and vibrant in burned sites and nearly dormant in unburned areas (Rondeau 2019). Cheatgrass never emerged and western wheatgrass, smooth brome, and mutton grass were all dormant. Grasses were dormant everywhere, however since they comprise most of the biomass in the unburned area, it was very noticeable.



**Figure 26. A burned plot (77-5D) in 2015, 2018, and 2019. 2015 and 2019 were wet years and 2018 was an extreme drought year. Note the bitterbrush growth between 2015 and 2019 as well as the reduction in cheatgrass from 2015 to 2019. In addition, the shrubs were vibrant during the 2018 drought while grasses were dormant.**



**Figure 27. An unburned plot (73-1D) in 2015, 2018, and 2019. 2015 and 2019 were wet years while 2018 was an extreme drought year. The shrub in the foreground is mountain mahogany, which was dormant in 2018. The pink flags mark Chapin Mesa milkvetch, which was also dormant in 2018.**

It appears that the species that were able to photosynthesize were different in burned and unburned areas. Trees appeared to take all of the available deep moisture in the unburned areas, leaving all the other species in a stressed or dormant phase, while shrubs were able to take the available deep moisture in the unburned areas. In addition, some Chapin Mesa milkvetch plants were able to emerge in the burned areas, however most were few stemmed, small, and without flowers or fruit. The post-drought year of 2019 was the extreme opposite with above average precipitation and recovery was very quick (Figures 26 and 27).

### **Density**

Chapin Mesa milkvetch is unevenly distributed, with higher densities occurring as one nears the cliff edges or goes south (downhill) on the cuesta. This variation is strongly correlated with two soil variables: clay content and organic matter. Organic matter alone can explain 72% of the variation in density, with high organic matter near cliff edges and further south. This information may be important if assisted migration became an important option for recovering this species.

The density of Chapin Mesa milkvetch initially had a positive reaction to the burn, including high recruitment. The benefit from the 2002 Long Mesa fire appears to have lasted approximately 10 years before beginning a reversal. By 2015 the beneficial aspect of the burn was no longer evident. From 2011-2019 the overall trend in burned areas was flat versus a slight upward trend in unburned areas

(0.006 slope). This suggests that either mortality or lack of recruitment (or both) is occurring in the burned areas but not in the unburned areas. Our demography plots allow us to categorize density by age class and while we do not have long-term data, we can easily discern a significant difference in age classes between burned and unburned areas. The age class distribution in the burned area is skewed toward immatures and adults with seedlings contributing approximately 9% to the overall density. Whereas, the age class distribution of the unburned areas is much more evenly distributed amongst age classes, with seedlings contributing 32% to the overall density.

Annual weather patterns are known to be important to plant density, reproductive output, and vigor, yet seldom do we know which climate attributes drive these metrics. The long-term belt transect data has allowed us to develop a strong correlation between winter precipitation and emergence of individuals. Wet winters precede high emergence and dry winters translate to low or no emergence. This pattern was evident regardless of burn history. Chapin Mesa milkvetch's deep roots coupled with a complete senescence each winter is conducive to taking advantage of deep soil moisture that is provided by winter moisture, primarily in the form of snow. Climate requirements for seedling emergence are associated with moist shallow soils in April and May. Seedling survival requires that the roots access deep soil moisture as soon as possible. Seedlings put most of their energy into growing deep roots, rather than abundant above ground biomass. While it appears that seedlings are a fairly common occurrence, the survival of young plants requires overwintering. The 2018 winter drought killed 2017 seedlings and yearlings, thus out of the 2015-17 seedling cohort, only the plants born in 2015 survived the 2018 drought.

### **Reproductive output**

We have moderately-high confidence that over 95% of the seed germination occurs in April-May and that seedling survival in burned areas is now significantly lower than in unburned areas; however, there is evidence that this was not the case in the first several years post-fire (Anderson 2004).

All reproductive success metrics (seedlings, yearlings, flowers, and fruits) were lower in burned plots vs unburned plots, 2015-17. The number of seedlings/adult was 5 times greater in unburned vs burned plots (median was 1.0 vs 0.2 seedlings/adult, respectively). The number of yearlings/adult was 3.6 times greater in unburned vs burned plots (an average of 0.11 yearlings/adult in burned vs 0.40 yearlings/adult in unburned). The proportion of adults that were reproducing was nearly twice as high in unburned vs burned (median was 0.7 vs 0.4, respectively). The median fruit production, 2015-19 combined, was 2.5 times higher in unburned vs burned (3143 vs 1259, respectively).

Based on five years of data on marked plants we can estimate survival rate of seedlings and immatures. For seedlings, we found a 9% and 32% survival rate in burned vs unburned plots, respectively. For immatures and adults we found a 78% and 97% survival rate in burned vs unburned plots, respectively. These survival rates suggest that mortality of all age classes is higher in burned vs unburned sites. The combination of low recruitment and high mortality of immatures and adults in the burned areas translates into a declining population.

### **Life span, mortality, and impacts from severe drought**

We have no confidence in the life span of an individual, but we surmise that an individual may live at least 15-30 years, if not more. Causes of mortality are unknown, although we suspect pocket gophers may be an animal that eats the caudex, given our field observations. . We observed very little mortality of adults in the unburned areas. We have evidence that prolonged severe droughts, such as 2018 may

kill some individuals, especially young plants. Annual monitoring of the marked individuals in the poker plots should allow us to determine average life span, mortality rate, and impacts from severe droughts. We may have the ability to determine longevity by counting rings from below the caudex.

### **Soil moisture and temperature**

Peak soil moisture at 35 cm depth occurred in mid-February to early March and then gradually declined until November, when it began to rise again. The summer monsoons never penetrated the deep soils. It appears that deep soils in the burned area may be around 5% drier than unburned soils, much of the year, however we need a longer data set to be confident in this number. In general, droughts often deplete soil moisture by around 5-10% (Rangwala pers. com. 2020). Shallow soil moisture varied much more than deep soils and was very sensitive to individual precipitation events, especially during the growing season, April-September. Our limited data set suggests that shallow soils in burned areas are significantly drier and warmer than unburned shallow soils, especially during the growing season. The temperatures of the shallow soils corroborate the soil moisture as soil temperatures were 3°F warmer during the spring and 7°F warmer during the summer in the burned areas.

The ecological impact of warmer shallow soil temperatures in burned areas vs unburned areas, during the late spring and summer seasons, may be greatest for seedling emergence and survival. The higher shallow temperatures coupled with high grass cover in the burned plots are likely to equate to drier soils and may help explain the low seedling survival in burned plots. For marked plants (poker plots), between 2015-2017, we documented a 9% seedling survival rate in burned (1 of 23 seedlings survived) and a 31% survival rate in unburned (18 of 59 seedlings survived). We surmise that the low seedling survival rate in burned areas may be associated with a shallow soil water deficit during the critical time (spring). It is likely that grasses are competing for the same shallow water resource as Chapin Mesa milkvetch. If that is the case, it may explain why initial recruitment was high after the 2002 burn, but has subsided in recent years. Grass cover was low in the initial years following the fire and has increased with time.

### **Post-fire conversion to grassland**

Prior to 2002, managers and botanists speculated on the effects of wildfire to Chapin Mesa milkvetch, with the understanding that this question was likely to become important as climate change became evident. Then in 2002, the Long Mesa wildfire burned nearly 40% of the population on Chapin Mesa, allowing our original 2001 belt transects to become the baseline information from which to detect the effects from fire. While monitoring was suspended from 2004-2010, we were still able to detect that the initial response was insignificant, that is, in 2003 there was no difference between burned and unburned areas. We were able to safely state that the majority of Chapin Mesa milkvetch individuals were not killed by fire. When we resumed monitoring in 2011 we detected higher densities in the burned transects vs unburned, allowing us to speculate that recruitment during the intervening years had been high in burned areas. We know that immediately following the fire, there was a flush of nutrients and low competition for soil moisture due to very little live vegetation, in fact Chapin Mesa milkvetch was one of the few species that emerged in 2003 (Anderson 2004). As time progressed, grasses, both seeded and non-seeded, became the dominant vegetation.

There is evidence that grass cover has increased since 2011 and may have become a serious competitor for shallow soil moisture. In 2011, Kuhn and Anderson (2012), established 61 permanent 30 m transects, utilizing the line-point intercept method in the burned area on Chapin Mesa. They collected cover data

for cheatgrass, western wheatgrass, smooth brome, and other grasses. While we have not repeated the 2011 plots, we can speculate from their data that grass cover has increased. Kuhn and Anderson (2012) observed that the average cheatgrass cover was 22%, while we found the average cover was 41% in our demography plots (2015-19). Western wheatgrass averaged 5% cover in 2011 vs 26% in 2016 and 19% in 2019. Kuhn and Anderson (2012) observed a combined grass cover of 42% in 2011 while our 2016 and 2019 observations of combined grass cover of cheatgrass and western wheatgrass were 63% and 45%, respectively. We surmise that a 42% overall grass cover in 2011 was still favorable to Chapin Mesa milkvetch recruitment, whereas 45% cover of cheatgrass and western wheatgrass combined is too much cover for seedling recruitment. Thus, we concluded that there was at least a short-term benefit to a wildfire as long as total grass cover remained below 42%. This pattern remained stable until 2015, when the pattern shifted and burned areas had less density of Chapin Mesa milkvetch than unburned areas. This coincided with an average cheatgrass/western wheatgrass cover of around 60%. Seedlings were fewer and survival of those seedlings was just 9% compared to numerous seedlings in unburned areas, with a 31% survival rate. As of 2019, it appears that the beneficial effects of the wildfire continue to degrade the vitality of CMM. The low recruitment and high adult mortality has shifted the burned area into a declining population while the unburned area remains stable.

For now, we can only speculate as to why this is occurring, and only time will tell if this trend will continue. We propose that the primary reason for the current low recruitment is due to high grass cover, primarily from cheatgrass, western wheatgrass, and smooth brome. Our largest concern is that these grasses may slow or inhibit the successional process of returning to a PJ woodland, and may have severe long-term consequences for Chapin Mesa milkvetch. While succession is notable, with shrubs and forbs increasing and grasses decreasing, the tide has not turned.

The effects of seeding after a wildfire suggest a potential to retard succession. Peppin et al. (2010) reviewed data from 16 sites contained in 14 studies assessing post-wildfire seeding effect of seeded grasses on shrub establishment in forested ecosystems in the western U.S. and found that shrub cover was greater in areas that were never seeded. Shrub cover is an important successional stage for post-fire PJ recovery as shrubs are often nurse plants for pinyon pine (Phillips 1909; Kane et al. 2015). Chapin Mesa milkvetch density started declining in 2015-16, and while we do not have firm evidence that this decline is caused by increased grass cover, the existing literature suggests that it is plausible. Western wheatgrass a perennial, sod-forming grass has abundant rhizomes and is a formidable competitor with bunch grasses and forbs. Western wheatgrass seedlings have been known to produce roots that extended to a depth of 76 cm (30") when 3 months old (Clements and Weaver 1924). Many of the roots of mature plants penetrated moist upland prairie soil to a depth of 2.4-2.7 m (8 to 9 feet) (Weaver 1920). Numerous, short, horizontal roots arise from the bases of the plants. Weaver (1942) found that height and seed production of other species growing within areas dominated by western wheatgrass were reduced compared to adjacent areas without western wheatgrass. The competition for water was also severe between the individual plants of wheatgrass and other species (Weaver 1942). Weaver (1942) found soil water content was often 3-8% higher in soils that had only bunchgrasses compared to soils dominated by western wheatgrass. The soil under western wheatgrass was always drier than under the prairie without western wheatgrass (Weaver 1942). The rate of water infiltration was 2.4 times as rapid in a bunch grass prairie vs a western wheatgrass stand. This accounts, in part, for drier soils in western wheatgrass dominated sites. Soil moisture depth was also significantly different for the same amount of precipitation: soils were wet to an average depth of 73.6 cm (29") under native prairie bunch

grasses vs only 26.4 cm (10.4") under western wheatgrass, illustrating the degree to which infiltration of water into soil covered with wheatgrass is reduced (Weaver 1942). Water loss from western wheatgrass was more than twice as much as from little bluestem, a bunch grass (Weaver 1942). In addition to reducing soil moisture, areas with western wheatgrass reduced the forb richness and cover. Forb species richness was reduced by 44% and number of stems reduced by 80% in areas dominated by western wheatgrass. This included forbs that were deep or shallow rooted. Competition for water resulted in great dwarfing and often in wilting and death of other prairie grasses and forbs.

Cheatgrass, a non-native annual grass that can emerge in either fall or spring has well documented competitive attributes, similar to western wheatgrass. Cheatgrass that germinates in the fall continues root growth throughout the winter, and initiates shoot growth earlier in the spring than native plants, meaning it reduces soil water content and has a large size advantage over spring-emerging forb seedlings (Arrendondo et al. 1998). Plants initially produce roots to depths of 18-20 cm before sending out far-reaching lateral roots. Cheatgrass roots can penetrate 87-150 cm or more, but are mostly concentrated in the top 30 cm of soil (Spence 1937; Hulbert 1955; Hironaka 1961). It uses more water earlier in the growing season than many native plants by initiating root and shoot growth at lower temperatures (Arrendondo et al. 1998) and exhibits greater root and shoot relative growth rates (Cline et al. 1977). The seedling stage of native species is vulnerable to competition from cheatgrass (Aguirre and Johnson 1991; Yelenik and Levine 2010). Parkinson et al. (2013) tested growth rates of big-seed biscuitroot (*Lomatium macrocarpum*), a tap-rooted forb with no lateral root branches (similar to Chapin Mesa milkvetch root), in addition to four other forbs. Total biomass after 12 weeks of growth were significantly lower (50%) when grown with cheatgrass. In addition, after 12 weeks of growth, total biomass of all forbs when growing with a native grass was not different from growing alone. In contrast, the total biomass of all forbs was reduced when growing with cheatgrass relative to growing alone (Parkinson et al. 2013).

While our study has not specifically addressed the hypotheses that grasses are impeding the recruitment and seedling survival of CMM and potentially reducing the succession towards a shrub/grassland state, the literature supports the notion that grasses could certainly be a reason for reduced vital rate and slower shrub increase. Future studies should attempt to address these questions.

Further investigation as to how the species composition, soil texture, soil moisture, and soil temperature correlate with CMM vital rates and population trend would assist managers in restoring burned areas and conserving unburned areas.

## CONCLUSION

Chapin Mesa milkvetch is a globally rare plant restricted mostly to Chapin Mesa at Mesa Verde National Park and Ute Mountain Ute Tribal Park. Mesa Verde National Park has responsibility for maintaining this plant. Without further information regarding the trend of Chapin Mesa milkvetch, we believe the largest threat to the population would be a large catastrophic fire in the unburned area of Chapin Mesa. Management plans that reduce the fire risk could be important. In addition, assuming a large fire is inevitable, a restoration seed mix should be developed and secured as soon as possible, ideally a diverse seed mix of around 50 species including grasses, forbs, and shrubs, limiting the grasses to a small percent of only bunch grasses, i.e., no western wheatgrass. If possible, we suggest adding CMM into the seed mix as there are abundant seeds during favorable years. We understand that Chapin Mesa has a

high visitor rate and that there is a desire to further develop areas. This undoubtedly will also impact the population, especially if the impact is in high density unburned areas. Any such direct disturbance should be mitigated for. Our monitoring results can provide insight into managers' decisions.

Monitoring a long-lived perennial requires repeated measures under different climate conditions and over multiple generations. Only then will we be able to answer valuable questions, such as how long can these plants live, or how old are they when they begin to produce abundant fruit? How long will it take for the burned area to return to densities found in the woodland? At what point along this succession path does the trend turn positive? How long before it returns back to pre-burn density, or at least a density that is similar to the unburned plots? How does a changing climate impact this species?

One thing we can be assured of is that continued monitoring will undoubtedly change this story. There are fundamental questions that still need to be answered in order to fully understand regeneration, mortality, and impacts from severe droughts, catastrophic fires, and increased temperatures. We graciously thank the National Park Service for their long-term commitment to protecting this species by learning about its ecological requirements.

### **Recommendations**

In order to discern trends and answer some fundamental questions, such as life span and impacts from severe drought and catastrophic fires, we recommend the following: 1) continue the current demographic monitoring effort through 2025, as well as data collection from soil moisture and temperature sensors (thus providing a 10-yr baseline for the demography plots in relation to soil moisture and temperature); 2) a re-sampling of all of Anderson's 2001 belt transects (Anderson 2001 and 2004) to assess overall population trend since 2001 (this should occur in 2025 if the 2024-25 winter has near average or above average winter precipitation); 3) resample Kuhn's 2011 (Kuhn and Anderson 2012) 30 m transects in the burned area to establish change in grass cover. Additionally, if possible, attempt to establish average life span using ring counts from CMM caudices. A reassessment of the monitoring program should occur in 2025 at the latest.

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APPENDIX 1 – Demography Plot Data 2015-2019: Burned vs Unburned Sites. (2018 not included due to extreme drought reducing the emergence to near 0).

Average of 11 plots		Burned				Unburned			
	Metric	2015	2016	2017	2019	2015	2016	2017	2019
Adults	total count	215	320	235	229	134	239	236	275
Immatures	total count	236	138	69	108	175	84	102	122
Imm+Adults	total count	451	458	304	337	309	323	338	397
Seedlings	total count	29	75	1	40	104	288	130	674
Yearlings	total count		43	19	0		98	92	0
Total Plants	total count	480	576	324	377	413	709	560	1071
Adults	Density (plants/m2)	0.20	0.29	0.21	0.21	0.12	0.22	0.21	0.25
Immatures	Density (plants/m2)	0.21	0.13	0.06	0.10	0.16	0.08	0.09	0.11
Imm + Adults	Density (plants/m2)	0.41	0.42	0.28	0.31	0.28	0.29	0.31	0.36
Seedlings	Density (plants/m2)	0.03	0.07	0.00	0.04	0.09	0.26	0.12	0.61
Yearlings	Density (plants/m2)	0.00	0.04	0.02	0.00	0.00	0.09	0.08	0.00
Density (plants/m2)	Density (plants/m2)	0.44	0.52	0.29	0.34	0.38	0.64	0.51	0.97
Total Flowers	total count	975	2051	460	4639.2	612	3679	543	6963
Total Aborted Flowers	total count			5142	27634.6			4641	49938
Total flowers and aborted flowers				5602	32273.8			5184	56901
Total flowers and aborted flowers/adult				24	141			22	207
Total Fruit	total count	1308	1181	1440	1210	2931	3335	1751	3824
Avg no. flowers/Adult	Reproductive output	4.5	6.4	2.0	20.3	4.6	15.4	2.3	25.3
Avg no. fruits/adult	Reproductive output	6.1	3.7	6.1	5.3	21.9	14.0	7.4	13.9
Avg no. seedlings/Adult	Reproductive output	0.13	0.23	0.00	0.17	0.8	1.2	0.6	2.5
Avg no. of yearlings/Adu	Reproductive output		0.13	0.08	0.00		0.4	0.4	0.0
Avg no. aborted flowers/	Reproductive output			22	121			20	182
Average browse (%)	Vigor		4	1.0			4.7	1.8	
Avg height (A&I)	Vigor	25	18.9	23.7		27	33	35	
Avg no. stems/A&I	Vigor	4	4.2	3.8		2.4	3.1	2.5	
Seedling/Imm and Adult		0.06	0.16	0.00	0.12	0.34	0.89		1.70
N		11	11	11		11	11	11	
sq meters		1100	1100	1100	1100	1100	1100	1100	1100

APPENDIX 2 – Total Count of Individuals (all age classes by year). Sorted from lowest density to highest density (2015) within burned plots (orange font) and unburned plots (green font) 2015-2019.

Plot	2015	2016	2017	2018	2019	Treatment
102-8D	9	12	11	0	8	B
102-2D	9	16	8	0	7	B
102-3D	13	21	14	1	24	B
102-7D	16	10	4	1	4	B
77-4D	16	21	20	11	25	B
78-2D	26	24	13	15	15	B
77-5D	40	41	32	11	28	B
78-1D	51	40	25	13	31	B
78-3D	63	40	20	15	32	B
77-6D	117	172	92	42	98	B
Sun temple	120	179	85	39	105	B
104-1D	4	8	6	0	5	UB
73-4D	10	19	7	0	24	UB
73-2D	14	17	21	0	28	UB
104-2D	18	31	22	0	24	UB
83-3D	25	52	26	0	85	UB
104-4D	33	36	33	0	62	UB
83-5D	34	52	52	0	235	UB
83-4D	35	72	58	0	105	UB
104-3D	56	78	67	0	90	UB
Sun point	80	184	124	0	177	UB
73-1D	104	160	144	0	237	UB
<b>Total</b>	<b>893</b>	<b>1285</b>	<b>884</b>	<b>148</b>	<b>1449</b>	
<b>Burned</b>	<b>480</b>	<b>576</b>	<b>324</b>	<b>148</b>	<b>377</b>	
<b>Unburned</b>	<b>413</b>	<b>709</b>	<b>560</b>	<b>0</b>	<b>1072</b>	

# APPENDIX 3– Soil Analysis Results

Tova Spector/Mesa Verde National Park  
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 Mesa Verde CO 81330



Colorado State University  
**Soil, Water and Plant Testing Laboratory**  
 Natural & Environmental Sciences Bldg - A320  
 Fort Collins, CO 80523-1120

DATE RECEIVED: 11-12-2018  
 DATE REPORTED: 02-13-2019

(970) 491-5061 FAX: 491-2930

BILLING:

## RESEARCH SOIL ANALYSIS

Lab #	Sample ID #	-----paste-----		Lime Estimate	% OM	-----AB-DTPA-----						
		pH	EC mmhos/cm			NO <sub>3</sub> -N	P	K	Zn ppm	Fe	Mn	Cu
R1970	sun point 10cm	7.5	3.9	high	3.4	4.4	4.22	155	0.33	22.3	6.76	5.93
R1971	sun point 35cm	7.6	3.4	high	3.8	2.1	4.07	127	0.39	10.8	5.61	4.40
R1972	83-3d 10cm	7.1	2.9	low	1.7	6.7	4.37	158	0.34	10.2	3.75	3.86
R1973	83-3d 35cm	7.0	3.1	low	1.2	0.4	2.76	164	0.30	11.3	7.93	4.97
R1974	78-3D 10cm	7.4	4.6	high	4.6	26.5	7.01	123	0.37	25.3	11.0	4.06
R1975	78-3D 35cm	7.9	2.7	high	1.7	1.9	2.89	63	0.12	5.84	2.23	1.96
R1976	78-1D 35cm	7.8	4.4	high	3.8	2.3	4.38	103	0.28	15.9	5.11	6.34
R1977	78-1D 10cm	7.7	5.0	medium	5.8	14.3	5.31	161	0.53	52.6	11.1	3.09
R1978	77-6D 10cm	7.7	4.7	high	2.7	14.1	8.26	137	0.38	16.3	9.84	3.44
R1979	77-6D 35cm	7.5	4.5	high	5.3	1.8	5.79	107	0.62	7.31	11.9	4.02
R1980	77-4D 35cm	7.6	3.7	low	2.1	10.5	7.92	158	0.62	16.4	7.73	3.26
R1981	77-4D 35cm	7.2	1.6	low	1.3	0.4	7.46	191	0.27	11.2	3.57	3.76
R1982	75-4D 10cm	6.9	1.6	low	2.0	2.1	3.29	181	0.23	12.2	4.23	3.40
R1983	75-4D 35cm	6.8	1.5	low	1.0	2.1	2.50	172	0.24	8.54	2.58	2.39
R1984	73-1D 10cm	7.7	4.1	medium	4.6	3.6	7.42	167	0.77	35.3	7.34	5.31
R1985	73-1D 35cm	7.8	4.1	high	4.5	0.9	5.18	106	0.36	12.3	2.96	4.94
R1986	104-4D 10cm	8.0	3.3	medium	2.3	1.2	3.50	96.3	0.25	12.4	3.36	3.60
R1987	104-4D 35cm	8.3	2.3	medium	0.6	1.0	1.70	74.4	0.35	5.56	1.68	2.25
R1988	102-8D 10cm	7.0	4.9	low	1.6	42.0	4.14	199	0.38	11.3	4.48	4.00
R1989	102-8D 35cm	7.1	2.4	low	1.3	5.2	5.39	179	0.43	10.8	5.87	2.58
R1990	102-3D 10cm	7.7	0.6	medium	2.9	16.7	5.81	157	0.64	12.9	14.6	4.20
R1991	102-3D 35cm	7.9	4.0	medium	2.2	2.1	4.42	131	0.34	8.68	8.93	3.89
R1992	104-3D 10cm	7.5	0.6	low	5.7	3.1	16.7	210	0.94	39.6	16.6	4.15
R1993	104-3D 35cm	7.7	0.6	medium	4.0	2.3	10.6	167	1.17	15.8	12.9	2.91

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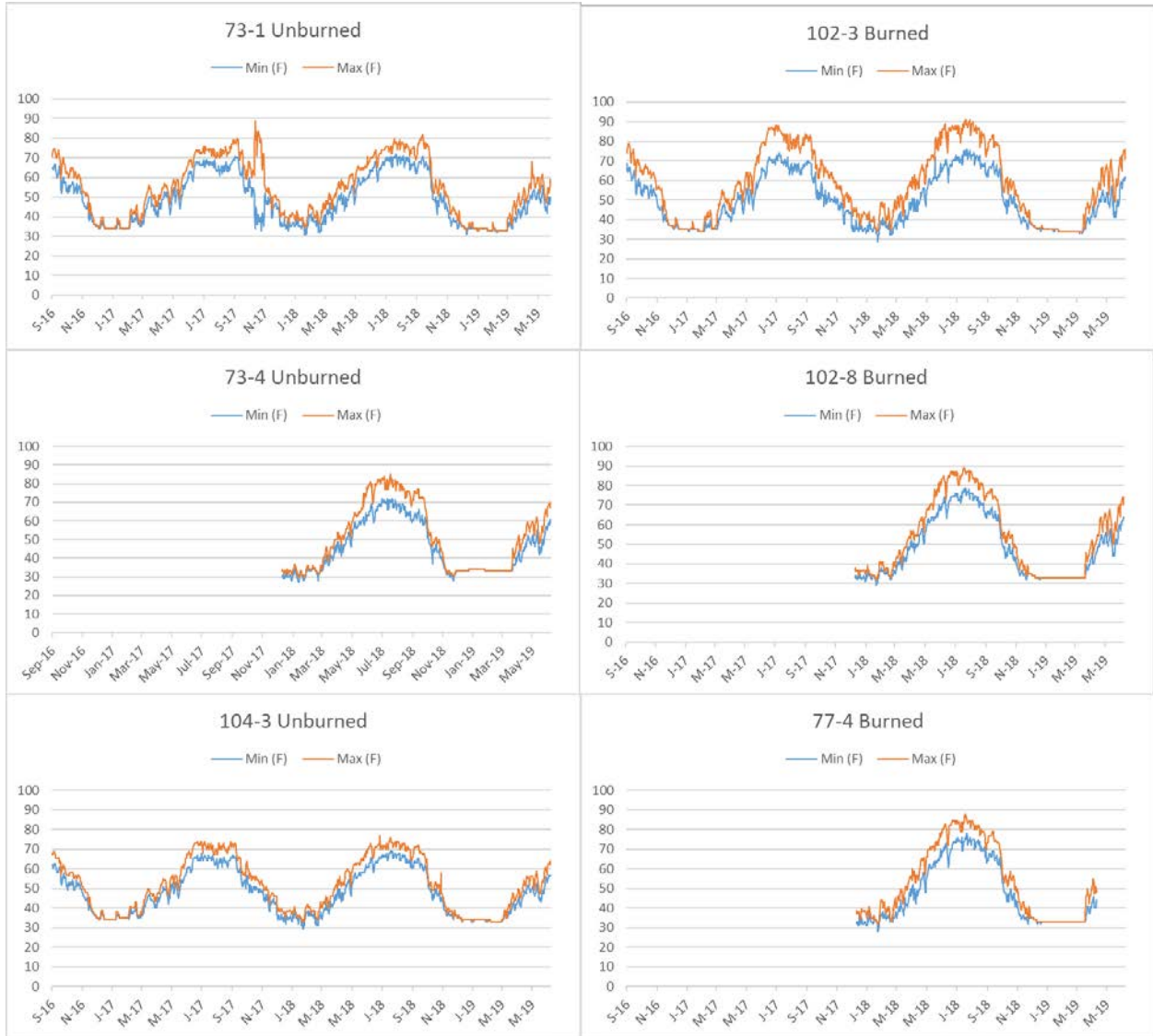
BILLING:

RESEARCH SOIL ANALYSIS

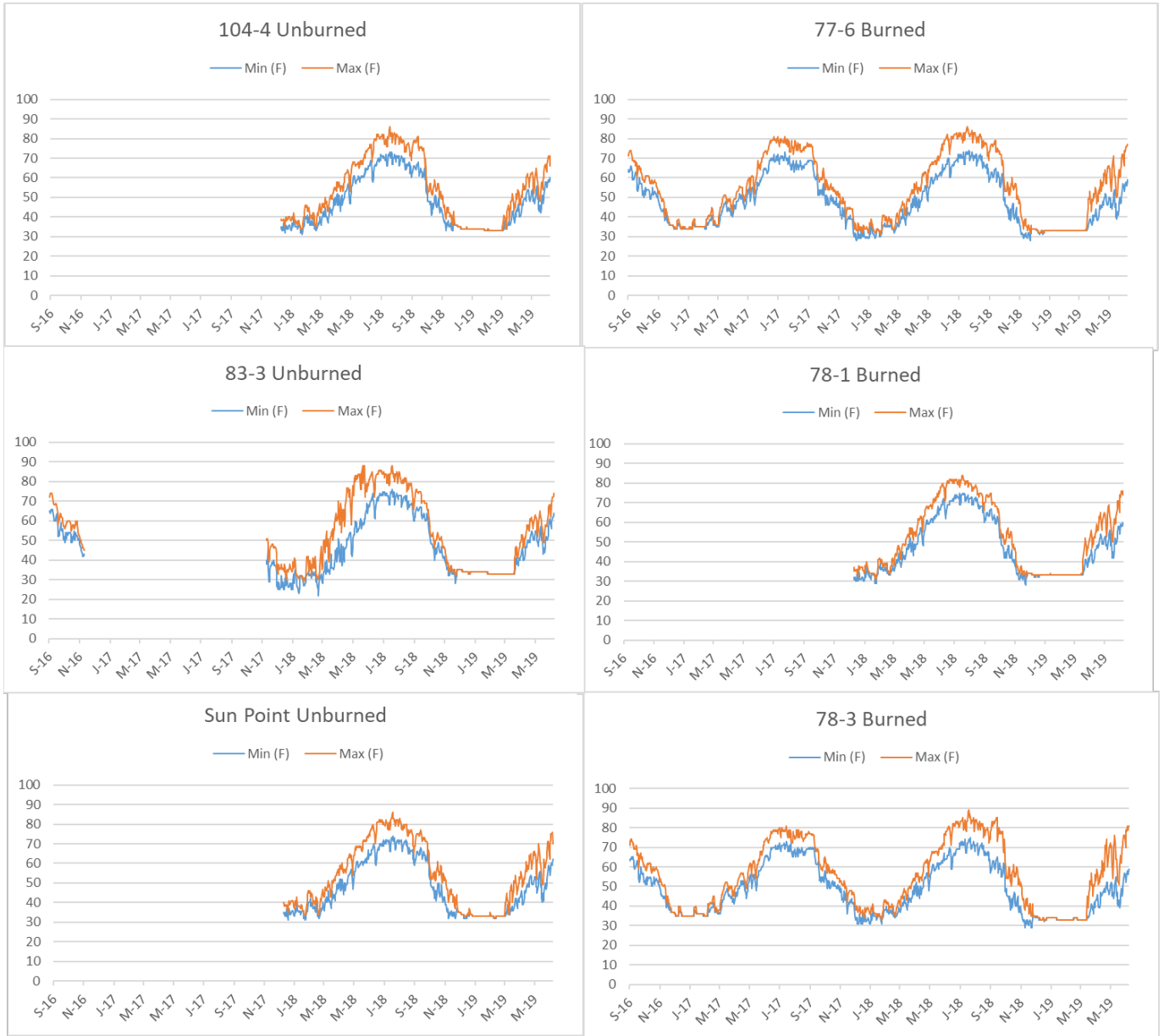
Lab #	Sample ID #	Sand	Silt %	Clay	Texture	-----bars-----		Available water capacity cm cm <sup>-1</sup>
						1/3	15	
						-----% H <sub>2</sub> O-----		
R1970	sun point 10cm	20	32	48	Clay	17.6	9.2	0.10587
R1971	sun point 35cm	24	24	52	Clay	16.7	8.5	0.10390
R1972	83-3d 10cm	20	32	48	Clay	17.0	8.9	0.10158
R1973	83-3d 35cm	20	32	48	Clay	20.3	10.7	0.11941
R1974	78-3D 10cm	24	32	44	Clay	18.2	9.9	0.10460
R1975	78-3D 35cm	16	28	56	Clay	18.8	10.1	0.11009
R1976	78-1D 35cm	20	28	52	Clay	21.5	9.8	0.14924
R1977	78-1D 10cm	20	36	44	Clay	19.8	10.0	0.12278
R1978	77-6D 10cm	16	36	48	Clay	17.8	9.2	0.10757
R1979	77-6D 35cm	12	36	52	Clay	20.3	10.8	0.11917
R1980	77-4D 35cm	20	36	44	Clay	14.7	7.9	0.08738
R1981	77-4D 35cm	16	36	48	Clay	16.7	9.1	0.09627
R1982	75-4D 10cm	12	40	48	Silty Clay	21.3	11.1	0.13210
R1983	75-4D 35cm	16	36	48	Clay	22.0	11.6	0.13205
R1984	73-1D 10cm	20	36	44	Clay	18.1	9.9	0.10453
R1985	73-1D 35cm	8	20	72	Clay	28.4	14.8	0.17165
R1986	104-4D 10cm	20	39	41	Clay	15.3	8.1	0.09053
R1987	104-4D 35cm	44	20	36	Clay Loam	13.2	6.9	0.07863
R1988	102-8D 10cm	20	36	44	Clay	18.5	9.9	0.10792
R1989	102-8D 35cm	16	36	48	Clay	22.1	11.8	0.13238
R1990	102-3D 10cm	16	36	48	Clay	20.1	10.7	0.12113
R1991	102-3D 35cm	24	35	41	Clay	20.1	10.5	0.11890
R1992	104-3D 10cm	20	36	44	Clay	14.7	7.8	0.08916
R1993	104-3D 35cm	20	36	44	Clay	15.8	8.2	0.09752

# APPENDIX 4– Shallow Soil (10 cm) Temperature 2016-19

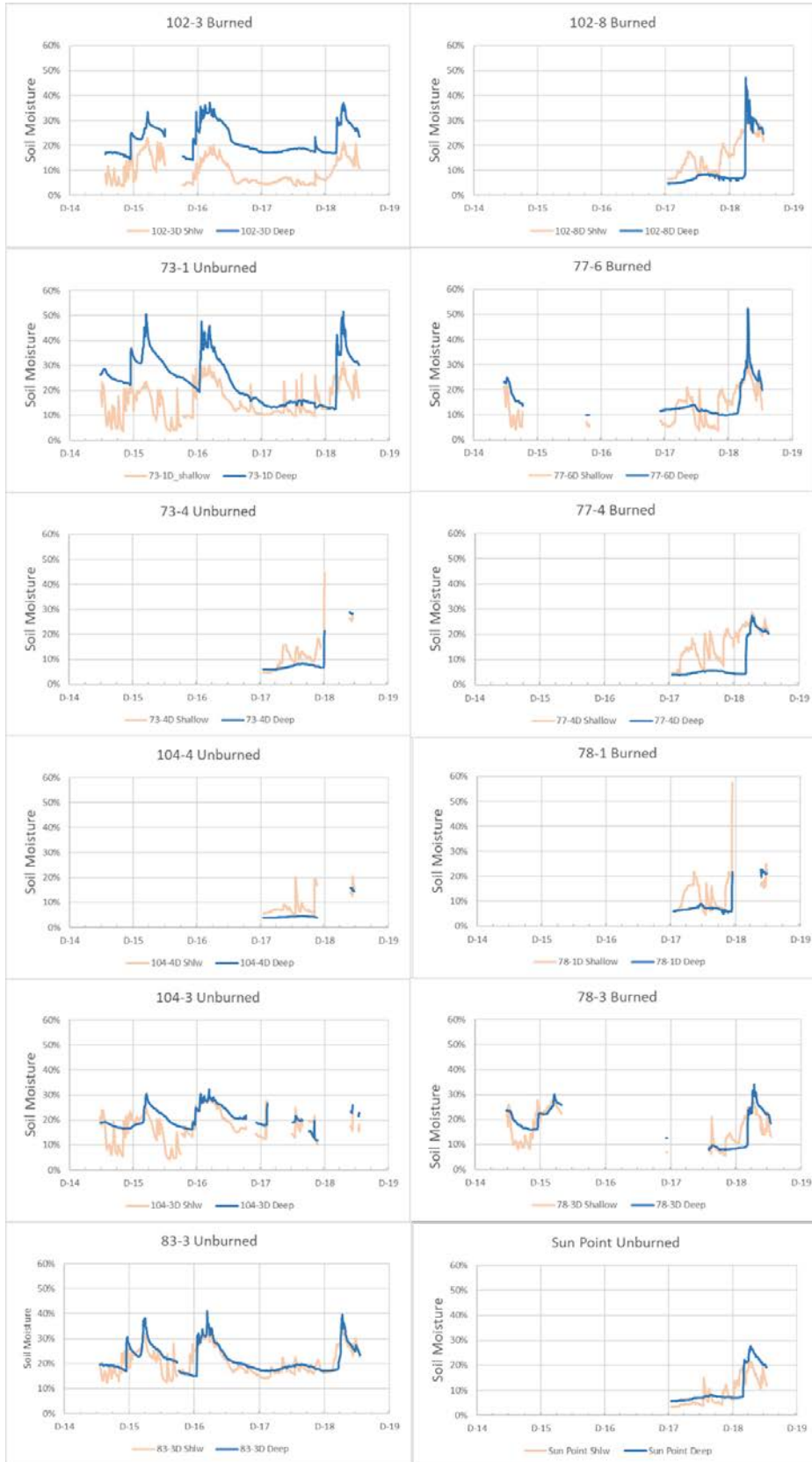
Minimum and maximum temperature for all plots. Unburned are on left and burned on right.



Appendix 4 Continued



# APPENDIX 5– Soil Moisture (10-35 cm depths) Data 2015-19





APPENDIX 6– Selected 2019 Field Photos



Chapin Mesa milkvetch in May snowstorm.



Searching for Chapin Mesa milkvetch.



Chapin Mesa milkvetch had copious stems and flowers in 2019 due to the extreme wet weather.



Plants in thinned woodlands near the southern border of the park were thriving.

