Long term Population Trends of Chapin Mesa Milkvetch (*Astragalus schmolliae* C.L. Porter)

2016 Report

Natural Heritage Program Colorado

Warner College of Natural Resources
Colorado State University

CNHP's mission is to preserve the natural diversity of life by contributing the essential scientific foundation that leads to lasting conservation of Colorado's biological wealth.

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2016 Report

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Cover photo: Demography plot on Chapin Mesa. Renée Rondeau 2016.

ABSTRACT

We collected density and demography data for Chapin Mesa milkvetch (*Astragalus schmolliae*) during the second half of May, 2016 and "poker plot" data one day during each summer month, June-August. Preliminary results suggest that 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. By 2015-2016 the recruitment and reproductive output in the burned area was far below that in the unburned woodland, suggesting that fires have an overall long-term negative impact, and that this species is essentially a woodland species. In 2015-2016, pollination (inferred), flowering, fruiting, seed germination, and seedling survival of the milkvetch were less in the burned areas. Our observations present multiple hypothesis as to why the burned areas are less favorable, including 1) seedlings are suppressed due to abundant cheatgrass cover, 2) lack of bare ground in burned area inhibits pollinators, 3) higher soil temperature in burned areas suppresses pollinators and seedling germination, 4) without tree cover for protection, late frosts are more likely to kill flowers in the burned area. Currently the burned areas are dominated by grasses, both native and non-native, with some shrub recovery evident but virtually no tree regeneration. Projected climate change is likely to increase the fire risk in the remaining woodlands. Post-fire management plans that encourage a rapid conversion from grassland to shrubland to woodland may be beneficial for Chapin Mesa milkvetch.

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INTRODUCTION

Species and Site Information

Chapin Mesa milkvetch (*Astragalus schmolliae*), in the legume family, is a deeply rooted herbaceous perennial that becomes dormant during the winter. The above-ground biomass withers away in the fall, and in spring new sprouts arise from the below-ground woody caudex. In favorable years, both flowers and fruits are present in late May. The species is characterized by showy white flowers, and downward curving pods. During severe droughts, most plants remain dormant (no above ground stems), and the amount of flowering and fruiting is also strongly affected by winter precipitation. Seedling years may be frequent, but our current demography plots will answer this question. Seedlings rapidly develop long tap roots. Germination can occur in April, May, and occasionally in June if there is adequate precipitation. Chapin Mesa milkvetch global distribution is 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 in MEVE, and from the West Chapin Spur. Like many rare plants, it is globally rare, but locally abundant throughout occupied habitat. It grows primarily in deep red loess soil on mesa tops in old-growth or recently burned pinyon-juniper woodlands between 6,500 and 7,500 feet in elevation. In 2002 the Long Mesa Fire burned a significant portion of the population, transforming the old-growth pinyon pine-juniper woodland into a grassland comprised of native and non-native herbaceous species with scattered shrubs.

Managing rare plants 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 CNHP and was declared a candidate for listing under the Endangered Species Act in 2010 (USFWS 2010).

Climate 2016

Compared to the 1971-2000 seasonal averages, the winter of 2016 winter had average temperatures and was 20% wetter than normal; while spring was 2° F warmer and 40% drier than average, due to a dry March (Fig. 2). A warm period occurred in mid-February, causing some snow melt (Fig. 1). In 2015, the average winter temperature was 4.5° F above 1971-2000 average while the precipitation was 22% wetter. Spring temperatures were nearly identical in both 2015 and 2016 at 2° F above 1971-2000 average, and spring precipitation was considerably wetter in 2015. Figure 2 and Table 1 summarize the differences.

Figure 1. Snow cover in February 2016. Winter moisture is a key variable.

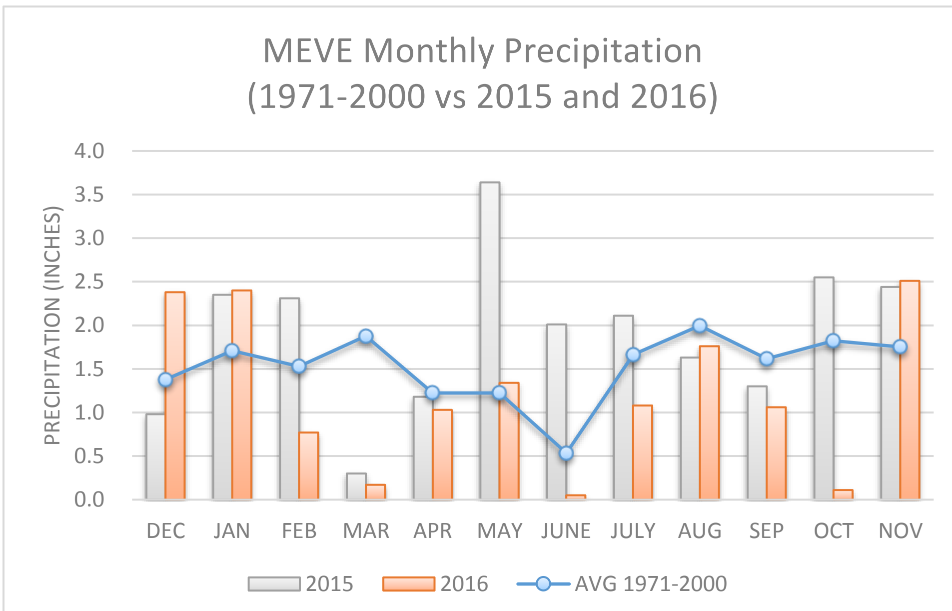

Figure 2. Chapin Mesa monthly precipitation for 2015-2016 compared to 1971-2000 average.

Table 1. Summary of winter and spring temperature and precipitation compared to 1971-2000 average.

Season	2015 (temp/precip)	2016 (temp/precip)	Notes
Winter	Hot and Wet	Average and Wet	2015 winter was 4.5°F hotter than average and 22% wetter; 2016 had an average temperature and was 20% wetter.
Spring	Warm and Wet	Warm and Average	Both 2015 and 2016 were 2°F above average; 2016 precipitation was above average and 2015 was average.

METHODS

We collected density data (plants/m^2) from belt transects that were randomly selected and established in 2001 (Anderson 2004) and reproductive output and vigor from demography plots established in 2003 and 2015. For density data, we re-sampled forty-four 100-m long belt transects that are 10 m wide and run east to west across Chapin Mesa. We compared plant density with Chapin Mesa seasonal precipitation data to assess any patterns associated with year-to-year variation. We re-sampled two 10 x 10 m, demography plots that were established in 2003: Sun Temple (burned in 2002) and Sun Point (unburned). In addition we re-sampled twenty 50 x 2 m demography plots (10 burned and 10 unburned), that were established in 2015, for a total of 22 demography plots equally split between burned and 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. All plants within the demography plots were classified as adult, immature, yearling, or seedling. Number of flowers, fruits, stems, and height were counted for each plant, in addition to percent browsed. We placed 1- m^2 frames 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 highlight individuals in the archival photo records. In addition to measuring plants, we collected soil moisture data continuously for a year at 5 and 35 cm depth at 6 stations adjacent to poker plots. Three of the stations are within the burned and three within the unburned transects.

RESULTS

Density, belt transects

This was our eighth year of measuring the permanent belt transects for density. We counted a total of 4423 plants, our highest count to date (2013 had 3952 plants and 2015 had 3711 plants). Prior to the 2002 Long Mesa Fire, milkvetch density was statistically indistinguishable between unburned and to-be-burned transects. Following the fire, relative density rose in the burned transects (significantly higher in 2011 and 2012), probably reflecting a nutritive or competitive benefits from the fire. 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. This year (2016) the negative effects of the burn approached statistical significance. Figures. 3 and 4 show strong year-to-year variation in density. The year-to-year variation in density is similar in burned and unburned transects (Fig. 3) and was strongly correlated with winter precipitation (Fig. 4 and 5).

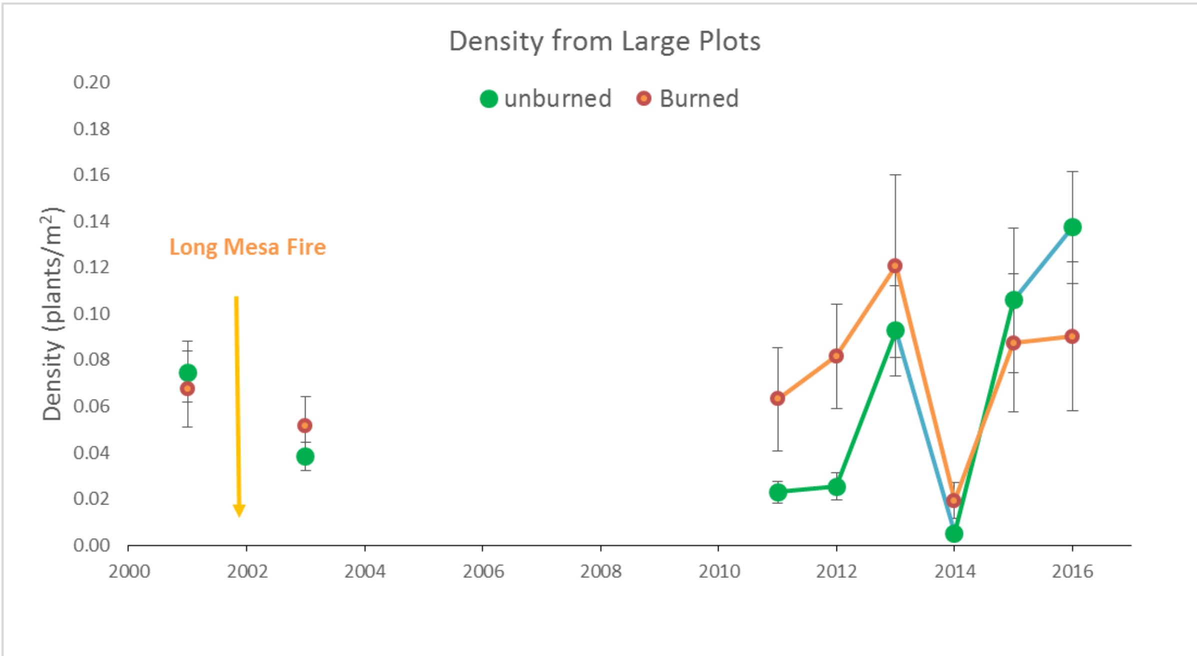

Figure 3. Average density (plants/m²) for burned transects (N=17) and unburned transects (N=22) with SE bars ± 1. After the 2002 Long Mesa fire and up until 2015, burned transects had higher density than the unburned transects, however by 2015 this trend reversed and the positive impacts from the fire appear to be reversing.

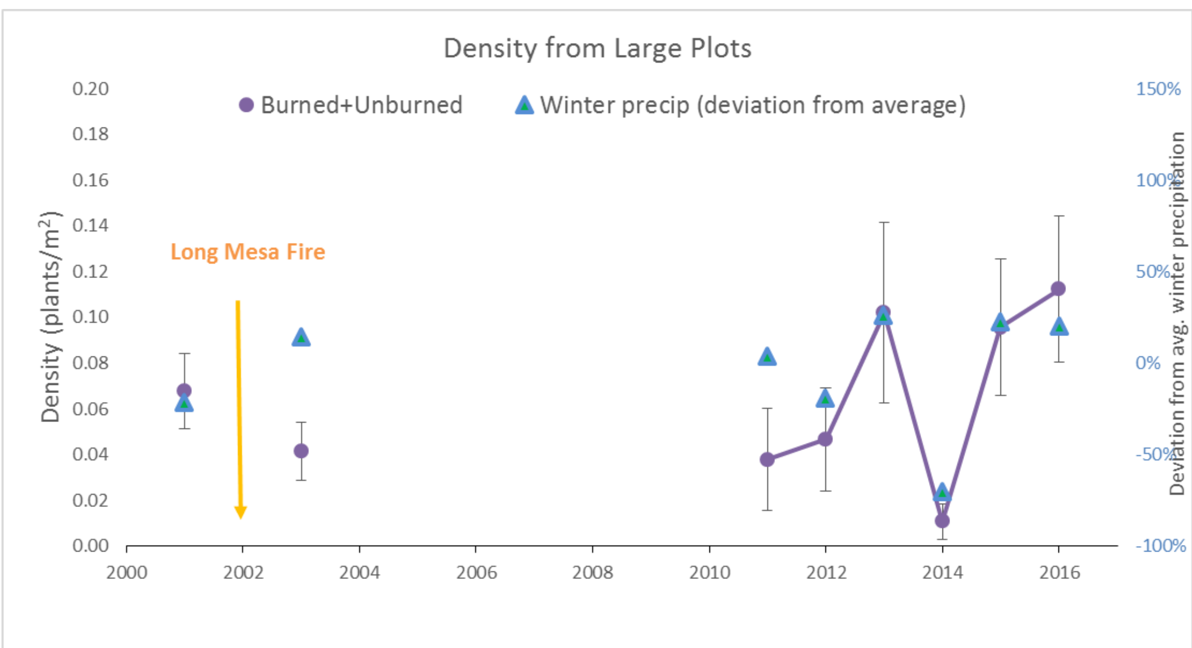

Figure 4. Year-to-year variation in density closely tracks winter precipitation. Years when winter precipitation is low, e.g., 2014 with 70% below 1971-2000 average, produced very low emergence of Chapin Mesa milkvetch. Basically there was not enough deep soil moisture to ensure growth and thus most plants remained dormant, whereas density was high in years when the winter precipitation was above average.

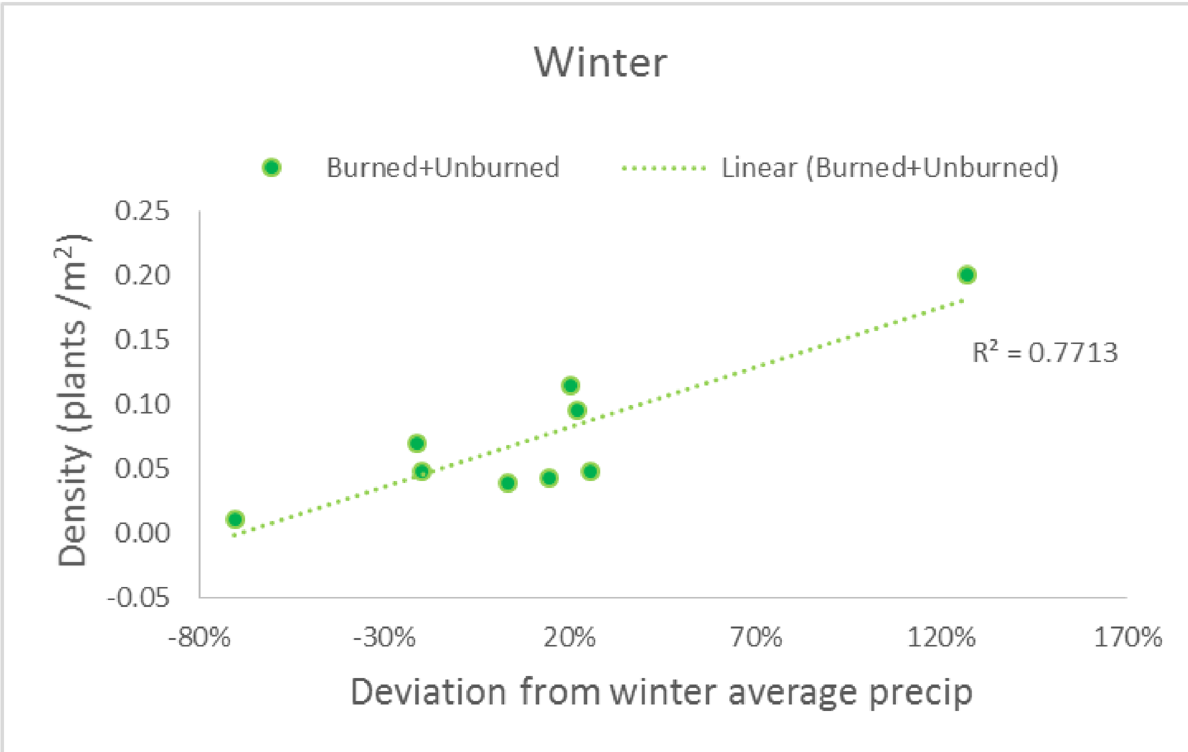

Figure 5. Linear regression analysis for all transects, regardless of burn treatment, 1980, 2001, 2003, 2011-2016. The association was highly significant (P = 0.00098 for two-tailed probability). All other seasons were tested for a correlation with Chapin Mesa milkvetch density, yet none were significant.

Density from demography plots

Note that the demography plots do not represent a random sample, thus they cannot be used to estimate population size or overall population density. The density plots from the belt transects (above) should be used to assess overall population trends in density. The demography plots can be used to compare reproductive output and age classes between burned and unburned. The total number of plants, or overall density, (plants/m^2) were similar between burned and unburned, but there were stark differences by age class (Table 2 and Figs. 6-7). Burned areas have more immature and adult plants and fewer seedlings and yearlings than unburned areas. On average there were 45% more immature and adult plants in burned areas, probably reflecting the reproductive flush following the 2002 Long Mesa Fire. The reverse is true for seedlings and yearlings. Burned areas had nearly 4 times fewer seedlings than the unburned area. Combining 2015 and 2016, we counted only 52 seedlings in the burned areas versus 196 in the unburned. This is likely due to the initial positive burn effect waning, and possibly reversing.

We can see a year effect with seedlings, but not with adult and immature plants. There was nearly 3 times the number of seedlings in 2016 compared to 2015. This result most likely reflects climate attributes. The wetter 2015 spring produced fewer seedlings than the drier 2016 spring. We are unclear as to why the wetter spring produced fewer seedlings. The onset of the 2015 spring was earlier than 2016, most likely due to the 4.5°F above average winter temperatures, but it is unclear if this weather pattern contributed to the number of seedlings.

Table 2. Average density (plants/m^2) from demography plots 2015-2016 for burn and year effects. For burn effect we averaged 2015-2016, and for year effect we combined burned and unburned. N=11 burned and 11 unburned; N=22 for year effect. See Appendix for 2015 vs 2016 burned and unburned data.

Age Class	Burned (plants/m^2)	Unburned (plants/m^2)	2015 (plants/m^2)	2016 (plants/m^2)
Adults	2.7	1.9	1.7	2.8
Immatures	1.9	1.3	2.1	1.1
Imm + Adults	4.6	3.2	3.8	3.9
Seedlings	0.52	1.96	0.7	1.8
Yearlings	0.2	0.5		0.7
Total Plants	529	561	447	643
Density (plants/m2)	0.53	0.56	0.4	0.6

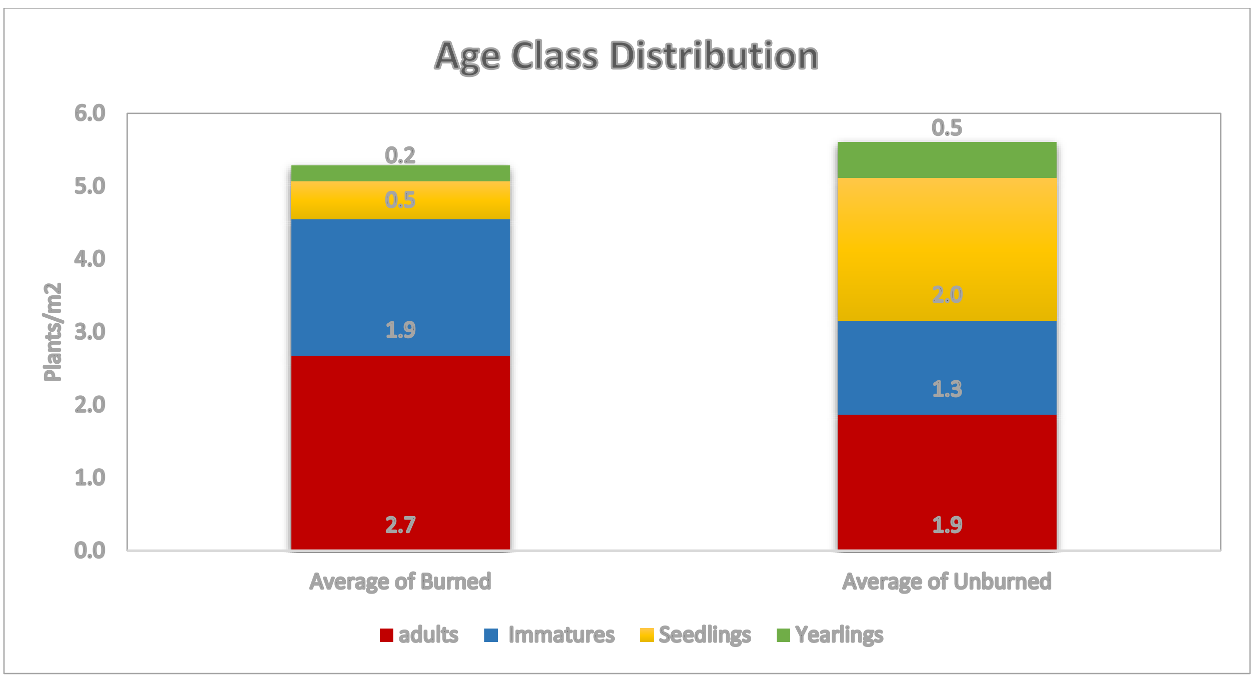

Figure 6. Total number of plants within each maturation class for burned and unburned transects, 2015-2016 average. Unburned transects had 4 times as many seedlings as the burned transects. (N=11 burn and 11 unburned).

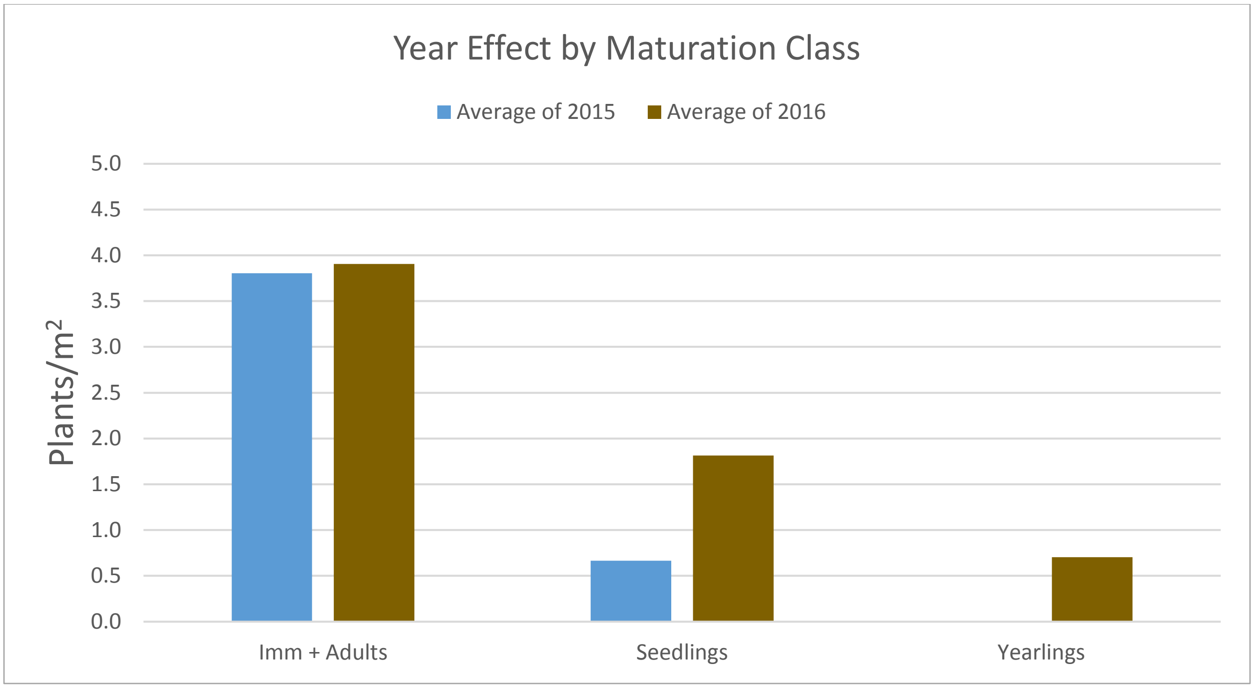

Figure 7. Total number of plants within each maturation class by year, 2015 and 2016. Burn and unburned transects were combined. N=22 for each year. There was no difference in immature and adult plants between years, however 2016 was a much better year for seedlings and yearlings. This difference was most likely due to the warm winter of 2015 compared to an average temperature in 2016.

Reproductive output, 2015-2016

The best metric for reproductive output is the number of flowers, fruit, and seedlings per adult. A burn effect compares the burned areas to unburned areas, while the year effect compares 2015 to 2016 and is useful for detecting variation due to climate. All of the reproductive output metrics were less in the burned than unburned areas. Burned areas had two times fewer flowers/adult than unburned areas; three times fewer fruits/adult; and five times fewer seedlings/adult (Table 3 and Fig. 8).

There was a year effect for all reproductive metrics. Our sampling occurred the last two weeks in May in both 2015 and 2016, yet flowering and fruiting were in different stages. In 2015 the flowering was past its peak and fruit production was in full swing. In 2016 flowering was peaking, and while fruit production had started, it was not as far along as in 2015 (Table 3 and Fig. 8). Both 2015 and 2016 were good seedling years, however 2016 was better than 2015 (0.5 seedlings/adult vs. 0.7 seedlings/adult, respectively). We surmise the higher flowering and seedling count is associated with higher soil moisture content at various soil depths due to a cooler 2016 winter.

Table 3. Reproductive output by burn and year effect. N=11 burned and 11 unburned; N=22 for year effect. Burned areas had less reproductive output than unburned regardless of metric. Year effect is most pronounced for flowers and fruit. This most likely reflects the difference in winter temperature, with 2015 4.5 F above average, allowing for earlier flowering and fruiting, due to warmer soils.

Age Class	Burned	Unburned	2015	2016
Avg no. flowers/adult	5.5	9.7	4.2	10.9
Avg no. fruits/adult	4.9	17.6	13.7	8.9
Avg no. seedlings/adult	0.18	0.99	0.5	0.7

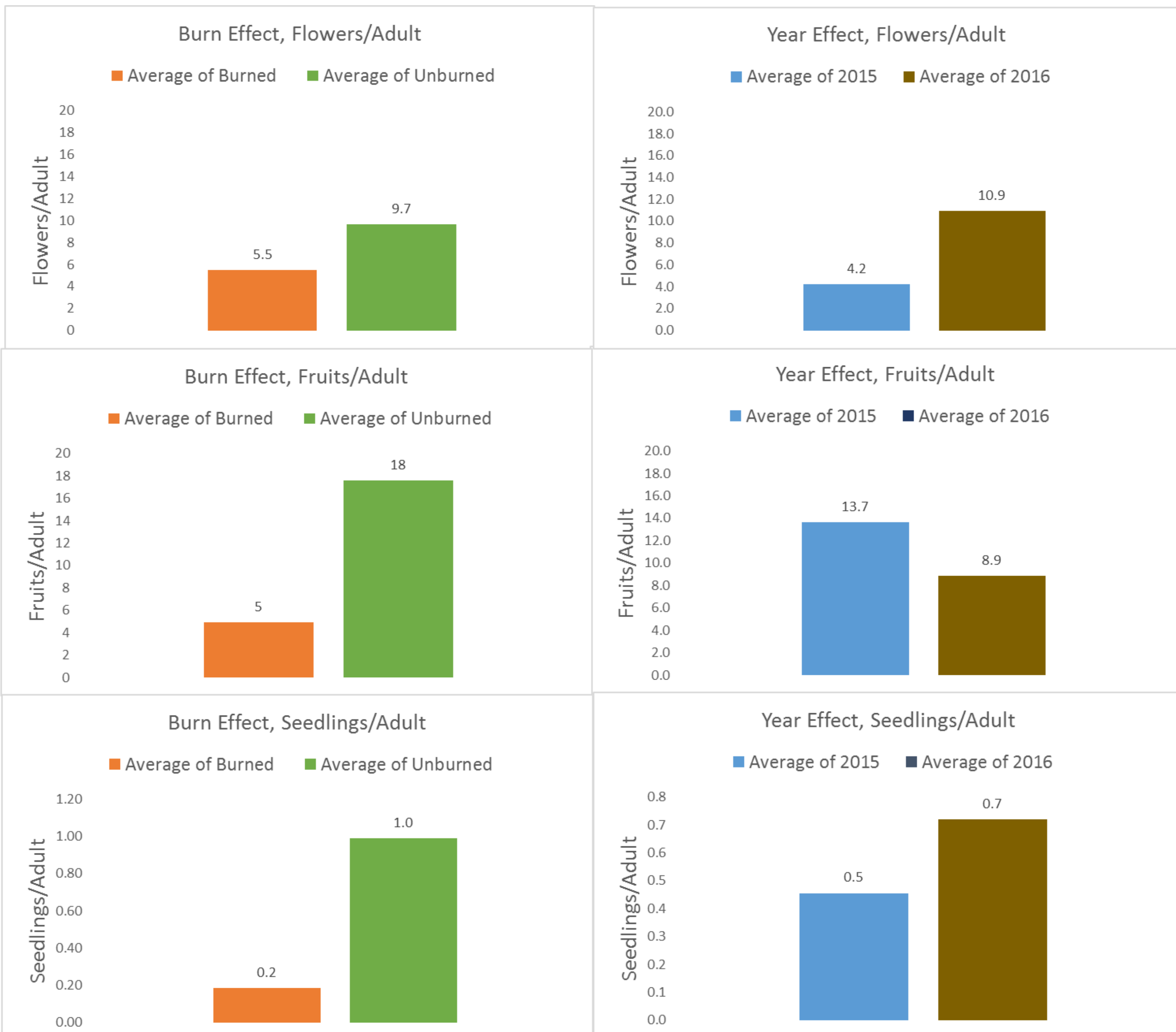

Figure 8. Burn and year effect for average number of flowers, fruits and seedlings/adult, 2015-2016. There were 5 times more seedlings/adult in the unburned than burned plots (2015 and 2016 combined). There were 40% more seedlings/adult in 2016 vs. 2015, potentially due to the cooler winter in 2016 as spring moisture was less in 2016 than 2015.

Seedling survival

Our 1 m^2 "poker" plots allow us to follow each marked plant from year to year. Of special interest are how the 2015 seedlings fared, i.e., how many of them survived to become yearlings. Of the 32 marked seedlings, 10 survived and were deemed yearlings in 2016; 8 in unburned and 2 in burned. The survival rate was 35% in unburned and 22% in burned. Two of the unburned seedlings were visible for only one sample period in 2015 (June), yet they re-emerged in 2016, indicating that seedlings have the ability to grow deep roots in a short amount of time, enough to withstand a serious browsing event (we surmise that browsing is what caused the plants to disappear from our view). From May-August, 2016, we re-sampled the poker plots and found that all but one of the yearlings survived the summer. Yearling number 1 in plot 104-4D (unburned) was only observed in May and June.

We also monitored the 2016 seedling success and by June, there was a 92% loss in the burned area vs a 35% loss in the unburned. Most seedlings that made it through the June drought were able to survive through August (Fig. 9). Out of 13 seedlings marked in burned plots during May 2016, only 1 was still visible in late June; in unburned plots, 18 of the 26 seedlings were still visible.

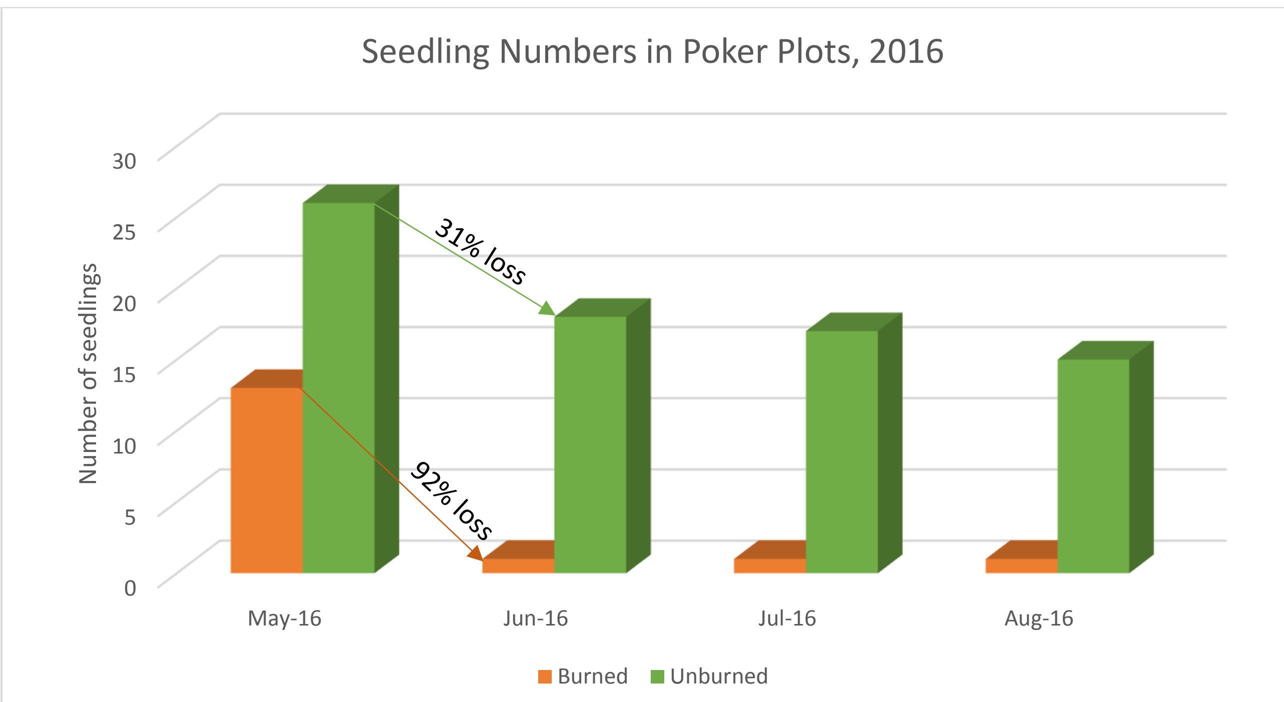

Figure 9. Seedling numbers in poker plots during May-August 2016. June was especially dry with only 0.05 inches of rain (average is 0.6 inches).

Sun Temple (burned) and Sun Point (unburned), 2003 vs 2016

These two demography plots were established in 2003, one year after the Long Mesa Fire (Anderson 2004). Anderson collected reproductive effort and vigor (number of stems/plant) and in 2016 we re-sampled. Our comparison of the two sample years depicts an initial reproductive flush in the burned area that has now reversed. Anderson (2004) found that fruit production was highest in the recently burned Sun Temple plot while it was nearly non-existent at Sun Point. Anderson (2004) concluded that it was likely that pollinators were drawn to the burned area in 2003, leaving plants in the unburned areas with insufficient pollinator resources. Plants in burned areas produced an average of 241 times more seeds per plant than in unburned plots in 2003. By 2016, this pattern was reversed (Table 4, Fig 10).

Since we have strong evidence that winter precipitation and temperature are important reproductive variables we compared 2003 with 2016. Winter precipitation was similar: in 2003 the winter precipitation was 15% above 1971-2000 average versus 20% above average in 2016. The 2003 winter was warmer than average (+2.6°F) whereas 2016 had an average winter temperature. So in essence, we believe the 2003 and 2016 important climate variables were similar with potentially 2016 being slightly more favorable.

Table 4. Sun Temple and Sun Point 2003 and 2016. Sun Temple burned in 2002. While there was an initial high reproductive output in the burned area, the trend was reversed by 2016. Orange text represents burned plots while green text represent unburned plots.

	Sun Temple 2003 Burned	Sun Temple 2016 Burned	Sun Point 2003 Unburned	Sun Point 2016 Unburned	Sun Temple Change (%) 03-16	Sun Point Change (%) 03-16
Seedling	85	25	123	98	-71	-20
Immature	121	77	14	39	-36	179
Adult	45	77	18	47	71	161
Imm + Adults	166	154	32	86	-7	169
Avg no. seedling/adult	1.9	0.3	6.8	2.1	-83	-69
Avg no. seedling/adult & imm	0.5	0.2	3.8	1.1	-68	-70
Avg no. flowers/adult	25.5	1.5	21.7	5.2	-94	-76
Avg no. fruits/adult	29.5	0.29	0.17	1.1	-99	547
Avg no. stems/adult & imm	3.67	1.8	2.39	1.5	-51	-37
Total Plants	251	179	155	184	-29	19
Density	0.251	0.179	0.155	0.184	-29	19

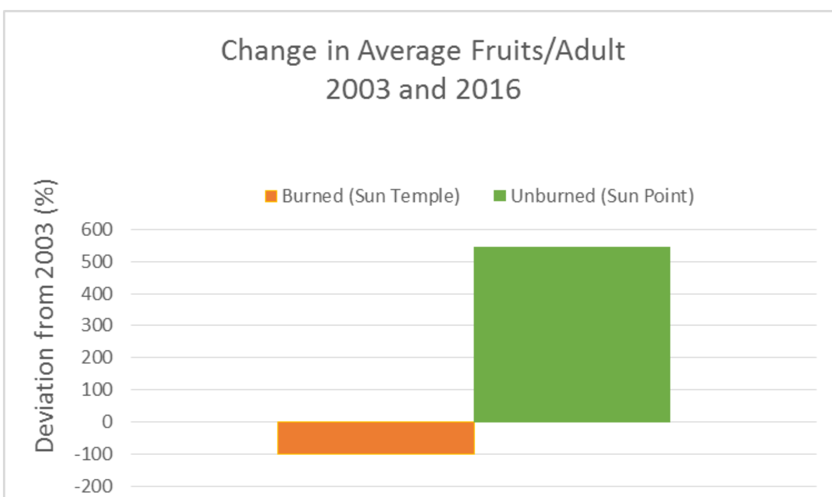

Figure 10. Change in average fruits/adult, 2003-2016. In 2016 the burned site had 99% fewer fruits/adult compared to 2003 while the unburned site exhibited an increase of over 500% in the average number of fruits/adult. We surmise that pollinators favored the burned areas in 2003, leaving the unburned areas. This pattern completely reversed in 2016, with fewer pollinators visiting the burned areas.

We speculate that by 2016, the flowers in the burned areas were not being pollinated, leading to fewer fruits/adult. We suggest counting aborted flowers in 2017.

Vigor, Cheat grass, and Browsing 2015-2016

Vigor is represented by height and number of stems/plant. In general, the plants in the burned areas are shorter and bushier (more stems) while plants in the unburned areas are taller with fewer stems. Vigor is not a surrogate for reproductive output.

Cheatgrass, a non-native species is just one of the many species that have been favored by burning (Floyd, et al. 2006). We use cheatgrass as a surrogate for grass cover since it is the dominant grass in most burned plots. On average there was 38% cover in the burned plots (ranged from 8-58%), a decrease from the 58% average cover of 2015, whereas we did not record any cheatgrass in the unburned woodlands. Grass cover, especially cheatgrass, may be inhibiting seedling emergence and survival, however this may not be the only issue of concern, e.g., higher soil temperature may be a concern. The decrease in cheatgrass does not represent a downward trend but instead represents an annual variation in timing and amount of precipitation or available soil moisture, especially during fall and spring.

Figure 11. Cheatgrass and wild horses in burned area.

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 (Figure 11), while cottontails appear to be abundant in both habitats. In 2016, we collected browse data based off of an observed difference in 2015. We did not find any difference in browsing between burned and unburned in 2016 (4% vs 4.7%, respectively), however additional years of browse data are warranted.

Soil moisture

Four out of the six soil moisture stations installed in May of 2015 performed flawlessly (all of the unburned, and the northern-most burned). Two stations, in the burned, had incomplete data sets, with 77-6D virtually unusable, and 79-3D with a near complete data set, minus April and May, thus it can be used for winter but not spring soil moisture. Average winter (December-February) soil moisture (N=5), varied from a low of 0.28 m^3/m^3 in unburned 104-3D to a high of 0.34 m^3/m^3 at unburned 73-1D (Fig. 14). The wettest winter soil moisture was at 73-1D (closest to the rim) and 83-3D (furthest south), they also had the highest average numbers of fruits/adult (16 and 30, respectively). Once we have multiple years and information for 77-6D we will have a better idea of the year-to-year and plot variation. Spring soil moisture (N=4, 3 unburned, 1 burned), was very similar amongst plots, except for 83-3D having higher spring soil moisture. The additional burned soil moisture stations are necessary to be able to make a comparison between burned and unburned. Among the unburned, the wettest spring soil moisture was also associated with the highest number of seedlings/adult (Fig. 13).

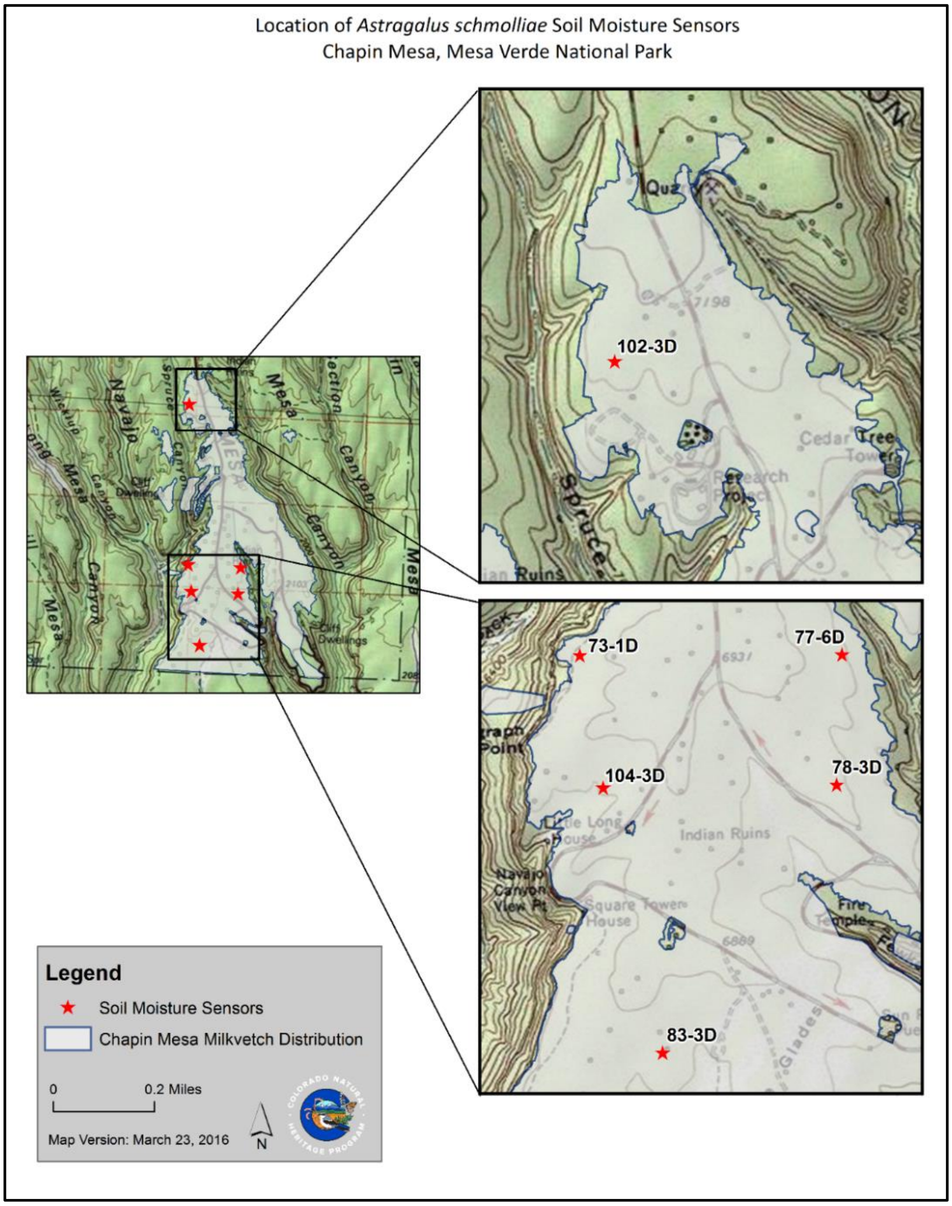

Figure 12. Location of soil moisture sensors installed on Chapin Mesa Milkvetch (*Astragalus schmolliae*) demography plots at Mesa Verde National Park. Burned plots are 102-3D, 77-6D, and 78-3D, unburned plots are 73-1D, 104-3D, and 83-3D.

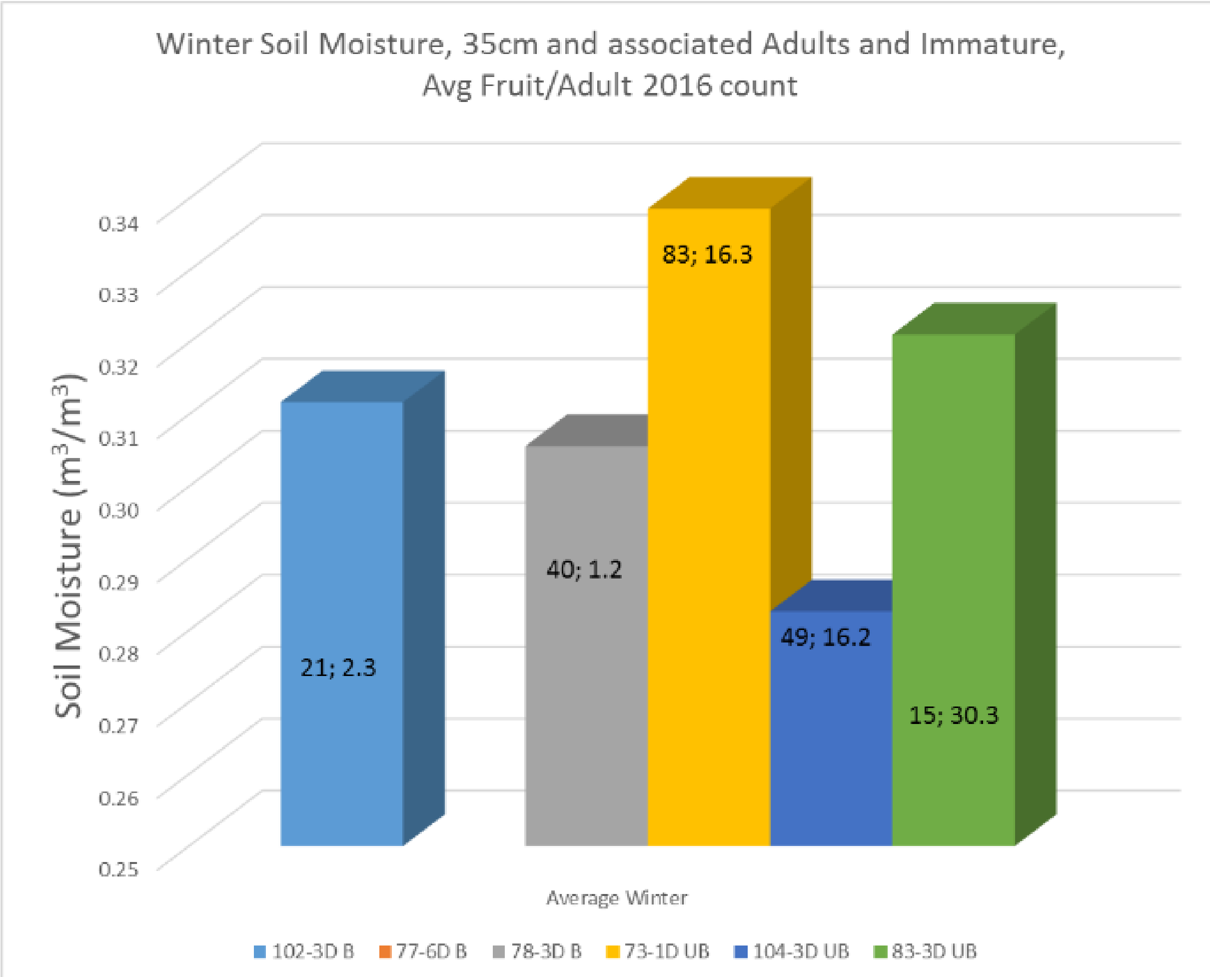

Figure 13. Average winter (December-February) and soil moisture at a 35 cm depth. The number in the bars represent the total number of immature and adults and average number of fruits/adult in 2016. The wettest winter plot, 73-1D also had the most number of adults.

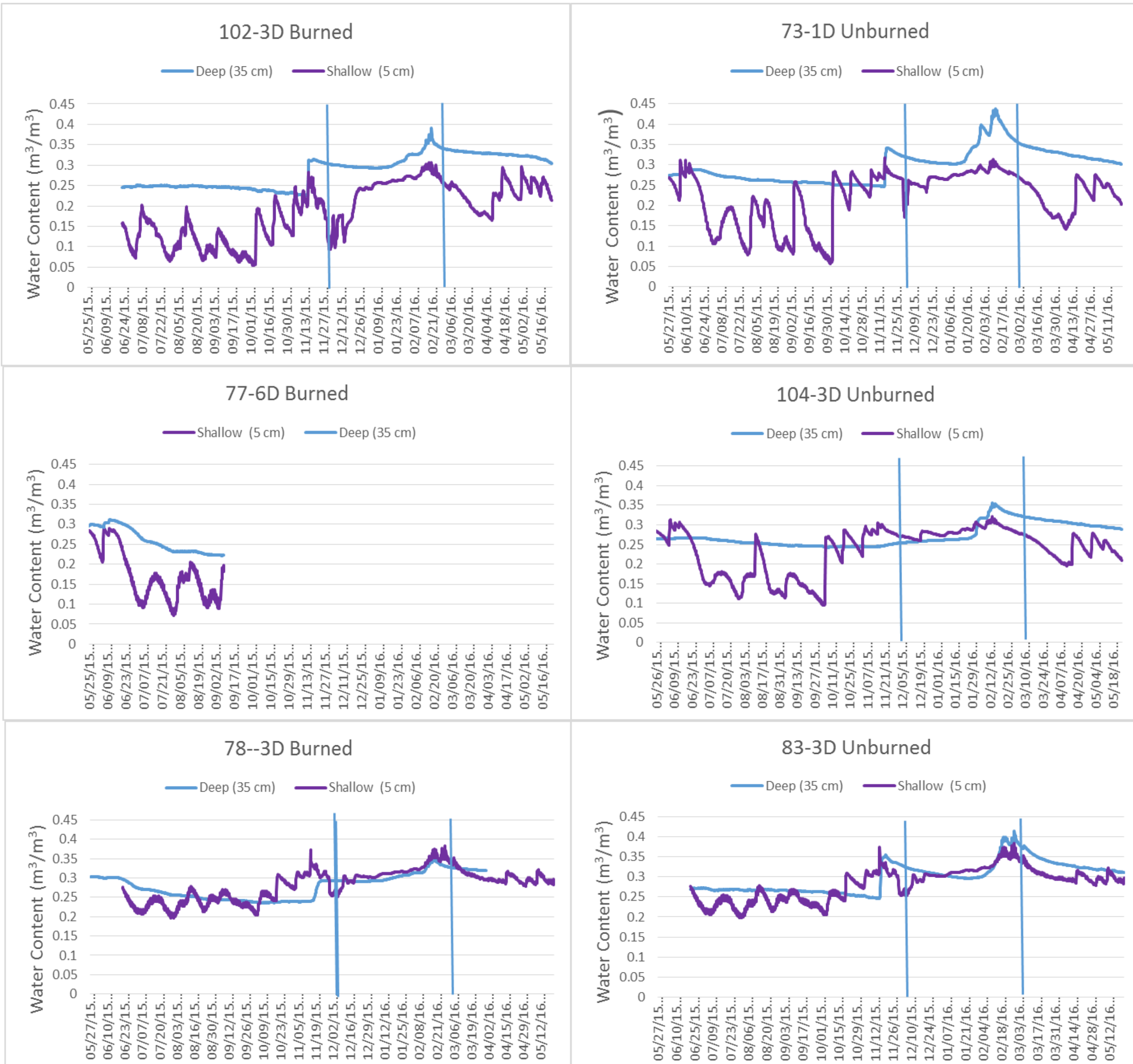

Figure 14. Deep (35 cm) and shallow (5 cm) soil moisture for all soil moisture stations. The vertical blue bars represent the beginning and end of winter (December 1-February 29). Top plots are furthest north and bottom plots are furthest south.

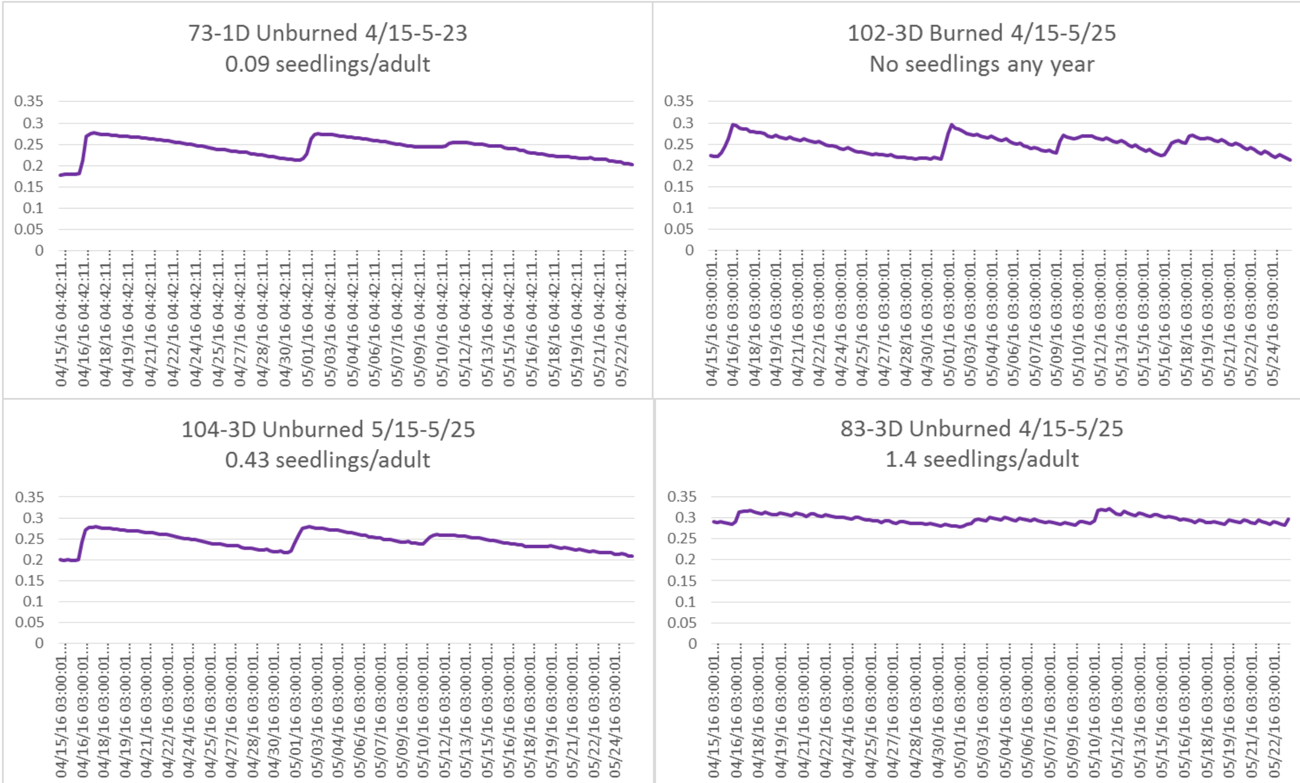

Figure 15. Shallow (5cm) soil moisture during spring (4/15-5/25) and their associated number of 2016 seedlings/2015 adult reported in heading. All but 83-3D have a similar moisture content; 83-3D was the wettest and did not dry out as much in between storm events. It also had the highest seedlings/adult.

DISCUSSION

Density

Overall density trends along our belt transects had a positive reaction to the burn that lasted approximately 10 years. By 2016 the beneficial aspect of the burn was no longer evident and suggests a potential downward trend, thus the burn is now a liability rather than an asset. 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 35% 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 density. Wet winters precede high density counts and dry winters translate to low or no emergence. This pattern was evident regardless of burned/unburned habitat. Chapin Mesa milkvetch's deep roots coupled with a complete die back each winter is conducive to taking advantage of deep soil moisture that is provided by winter moisture, primarily snow. Climate requirements for seedling emergence and survival is not well known but we are hopeful that we can derive a few hypothesis after we collect 2017 data. We surmise that spring moisture is critical but that winter moisture is also an important variable, as the seedlings survival relies on growing deep roots quickly.

Reproductive output

While winter precipitation was nearly the same in 2015 and 2016 (22% and 20% above average, respectively), we noticed a year effect in flower onset, with 2015 plants setting flowers earlier than 2016. Spring temperatures were nearly identical in the two years, at 2° F above 1971-2000 average, and spring precipitation in the two years were average or above average as (Fig. 1). Winter temperatures were different between the two years, with 2015, 4.5° F above average, and 2016 average (Table 1). It is potential that the warmer winter in 2015 led to a quicker snow melt leading to early soil warming and early blooming. The warmer soils likely also translated into reduced deep soil moisture by late spring. Our photos and data suggest that plants were larger in 2016, especially in the unburned areas, whereas plants were taller and had more stems in 2016 vs 2015 (see photo in appendix). It is important to note that nearly all climate projections predict warmer winters, such as 2015, becoming the norm.

Although we do not yet have enough data to estimate average mortality of Chapin Mesa milkvetch in differing conditions, our measures of recruitment point to a net reduction in recruitment in the burned plots. This contrasts sharply with Anderson's 2003 assessment (Anderson, 2004). In the year immediately after the fire, Anderson (2004) found substantially greater recruitment in the burned plots. One would expect this burn area advantage to diminish over time as the burned areas naturally return to their pre-burn condition. If burned areas experience a transient boost to recruitment (with no offsetting increase in mortality), that slowly subsides back to pre-burn conditions, the net effect of a burn would be positive for Chapin Mesa milkvetch. However, the apparent recruitment benefits from the 2002 Long Mesa fire have diminished and reversed over the last four years, such that the burn effect on recruitment now appears to be negative. There was significantly lower reproductive output in burned areas than unburned areas, in spite of the fact that there were more adults and immatures in the burned plots. Anderson (2004) found a similar pattern on Park Mesa. Park Mesa burned in 1996 and originally had a flush of reproductive output (Floyd-Hanna 1999), however by 2003 that trend had been reversed and Anderson found more aborted flowers, leading to less fruit production. In addition Anderson did not find any seedlings within the Park Mesa burned area but he did find seedlings in the unburned Park Mesa area. Anderson (2004) also established two demography plots on Chapin Mesa (one burned and one unburned), one year after the 2002 Long Mesa fire. We re-sampled these plots in 2015 and 2016 and found the same pattern. See result section for details.

Seedlings

We documented higher seedlings in 2016 than 2015, yet 2015 was a wetter spring than 2016 and temperatures were nearly equivalent, at 2.5°F warmer than the 1971-2000 average. While it is possible that 2015 was too wet for seedlings, it is more likely that winter temperatures coupled with winter moisture is also important. Both 2015 and 2016 winter moisture was nearly identical at 22% and 20% above 1971-2000 average, respectively. The difference was in temperature, with the winter of 2015 relatively hot, at 4.5°F above 1971-2000 average, while 2016 had average winter temperatures. It is likely that the warmer 2015 winter reduced soil moisture earlier than average and therefore provided less soil moisture for seedling survival than 2016. It is also possible that soil temperature differed and impacted seedling germination. Our soil moisture sensors and the addition of soil temperature sensors should eventually help us understand the relationship between temperature, precipitation, and shallow and deep soil moisture. June 2016 was exceptionally dry and nearly all the seedlings in the burned area died (92% loss), while the unburned seedlings fared much better with a 31% loss. June of 2015 was exceptionally wet and seedlings continued to emerge. Seedling emergence during the monsoons was virtually non-existent in both 2015-2016. In addition to a year effect, we found a strong burn effect with 75 total seedlings in the burned vs 288 in the unburned. In summary, the burned areas produced fewer seedlings and had a low survival rate, whereas the unburned areas produced numerous seedlings and had a high survival rate.

Possible scenarios for lower reproductive output in the burned plots:

1) The high grass cover including a high percentage of cover of non-native grasses in the burned area suppress seedlings.
2) There is a difference in soil moisture and temperature—soil dries out faster and soil temperatures are hotter in burned areas, leading to lower reproductive output, especially seedling germination.
    a. Need more soil moisture data, but at first glance shallow soil moisture does not appear to be different between burned and unburned.
    b. Difference between burned and unburned plots in shallow soil temperature. Our data loggers in the burned plots didn't work due to moisture seeping into the logger case. Perhaps shallow soil temperatures were higher in the burn (a greater differential inducing more condensation in the logger cases?) and potentially shallow warm soils aren't good for germination. Friedlander (1980) subjected Chapin Mesa milkvetch seeds to various temperature regimes and germination decreased with temperature increases.
3) Lack of pollinators in burned sites leads to fewer fruit? We casually observed more aborted flowers in the burned than unburned sites. In contrast, Anderson (2004) noted more pollinators in burned versus unburned sites. (We suggest counting aborted flowers in 2017).
4) Burned sites may be more vulnerable to late killing frosts.
5) More browsing in burned than unburned, leading to fewer flowers and fruits.
    a. Our 2016 browse data did not support this, however multiple years of data may be necessary to capture this difference.
    b. Number of browsing species appeared to be higher in burned sites and included pocket gopher, rabbits, deer, horses, grasshoppers, whereas the unburned sites have only deer and rabbits.

The typical seral stages for Pinyon-Juniper Woodlands after a burn, is for the area to succeed from a grassland to a shrubland to a woodland. This process is likely to require over 100 years, and some 200 years to return to old-growth. During the fall of 2015, pinyons produced numerous seeds. During our 2016 sampling we observed and photographed numerous pinyon seedlings in the unburned areas yet we did not see any pinyon or juniper seedlings in the burned areas. Shrubs continue to increase in the burned areas, based on long-term photo points of Sun Temple, yet tree regeneration did not occur in our plots. Since fire size, frequency, and severity are more likely to increase with a warmer climate, a post-fire management plan that encourages a more rapid conversion from grassland to shrubland to woodland would potentially benefit Chapin Mesa milkvetch. In addition, re-seeding with native bunch grasses and forbs and possibly shrubs may enhance recovery time. Preventing fires or other ground disturbances in the remaining Chapin Mesa old growth is critical as we advance our knowledge.

Since 40% of Chapin Mesa in MEVE burned in the 2002 fire, and Chapin Mesa milkvetch reproduction now appears to be declining (compared to unburned conditions) within the burned area, we suggest that Chapin Mesa milkvetch may not experience a net benefit from fire over the decades required for forest regeneration, especially if the area remains in a grassland for decades. Once we understand the average life span of Chapin Mesa milkvetch, we may have a better understanding of the tradeoffs involved. Colyer (pers. comm. in Anderson 2004) stated that she believes the plants are likely to reach 20 years of age, actual data will require long-term monitoring of marked individuals. Long-term persistence of the seed bank, and long-term frequency of germination are also critical but unknown. Weather variation may alternately favor or disfavor burned plots over unburned—only long-term monitoring of the demography plots will tell us that.

It is important to note that while the 2015-2016 demography plots had very distinct differences in proportion of maturation classes, number of fruits/adult and seedlings/adult in the burned vs unburned plots, we are not confident that this pattern will persist unchanged in future years. It may be that we will see years where the opposite outcomes prevail, especially when we experience a different weather pattern.

Soil moisture sensors

Our first attempt to measure soil moisture at 5 and 35 cm depths at 3 burned and 3 unburned sites went well in the unburned areas, and failed in the burned areas, due to moisture seeping into the loggers. Two of the three loggers in the burned area had to be refurbished, thus it was necessary to reconfigure the infrastructure to ensure that loggers remain dry. In order to keep this from re-occurring, on September 5, 2016 we placed all data loggers in a water proof Pelican Box 1150 series and added an EL-USB-1 temperature data logger into the box (Fig. 15). The Pelican Box was buried so that the top of the box is 10 cm below the surface, thus temperature data will be acquired for the 10 cm depth. The soil moisture sensors were placed at 10 cm and 35 cm depths. Multiple years of soil moisture data will be required in order to detect the patterns of interest.

Figure 15. Refurbished soil moisture logger in Pelican box (left) and placement of box at 10 cm from surface (right).

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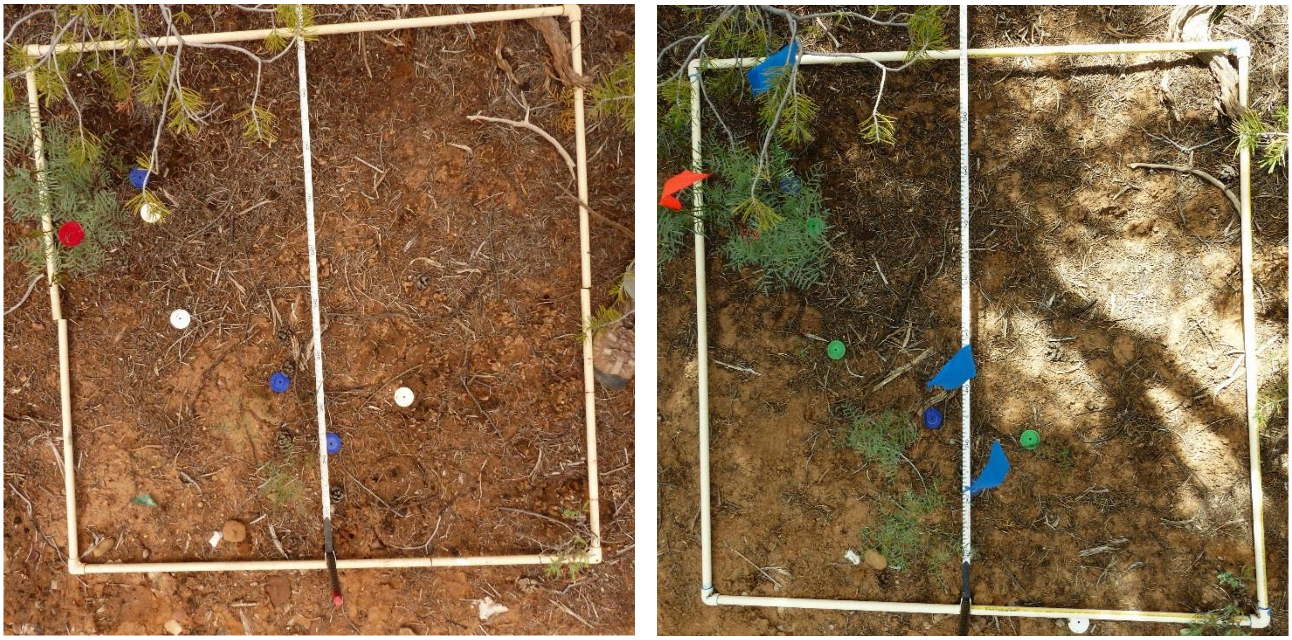
APPENDIX I – Burned vs Unburned data 2015-2016

	Metric	Burned 2015	Burned 2016	Unburned 2015	Unburned 2016
Adults	Density (plants/m2)	2.15	3.2	1.34	2.39
Immatures	Density (plants/m2)	2.37	1.38	1.75	0.84
Imm + Adults	Density (plants/m2)	4.52	4.58	3.09	3.23
Seedlings	Density (plants/m2)	0.29	0.75	1.04	2.88
Yearlings	Density (plants/m2)	0	0.43	0.00	0.98
Total Plants		481	576	413	709
Density (plants/m2)	Density (plants/m2)	0.48	0.58	0.41	0.71
Total Flowers		975	2051	524	3679
Total Fruit		1308	1181	2837	3355
Avg no. flowers/Adult	Reproductive output	4.5	6.4	3.9	15.4
Avg no. fruits/adult	Reproductive output	6.1	3.7	21.2	14.0
Avg no. seedlings/Adult	Reproductive output	0.13	0.23	0.78	1.21
Average browse (%)	Vigor		4		4.7
Avg height (A&I)	Vigor	25	18.9	27	33
Avg no. stems/A&I	Vigor	4	4.2	2.4	3.1

APPENDIX 2 - Selected photos to represent findings



104-4D poker plot, May 2015 and May 2016. White chips are seedlings and green chips areyearling. All three seedlings in 2015 became yearlings in 2016. The adult (red chip) and immatures (blue chips) also survived. Adult and immatures in 2016 were larger than in 2015.

Most plants appeared larger in 2016 vs 2015, potentially due to the cooler winter temperatures. Top photo is from 2015 and bottom in 2016, both late May photos (83-5D).

Seedling on left and yearling on right. A seedling is generally around 3-4 cm tall when we measure it in May while the yearling is approx. 15-18 cm tall.

Jabus Smith counts Chapin Mesa milkvetch flowers.

Melissa Nicoli counts Chapin Mesa milkvetch flowers.

Melissa, Tova, and Drew search for Chapin Mesa milkvetch along the density belt transect.

David and Al collect Chapin Mesa milkvetch data along demography plot.

Tova Spector counts Chapin Mesa milkvetch flowers and fruits.

. Fruits on a plant in the unburned and flowers on a plant in the burned area.