Long Term Population Trends of *A. schmolliae* (*Astragalus schmolliae* C.L. Porter)

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Cover photo: *Astragalus schmolliae*, Schmoll's milkvetch, growing through cracks in the red loess soils of Mesa Verde National Park. Photo by David Anderson.

TABLE OF CONTENTS

Figures and Tables

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ABSTRACT

Astragalus schmolliae (Schmoll's milkvetch) is an herbaceous perennial in the legume family. Among Colorado's rarest plant species, its global distribution is constrained almost entirely to Chapin Mesa within Mesa Verde National Park (MEVE) and the adjoining Ute Mountain Ute Tribal Park. In 2010, *A. schmolliae* was added to the list of candidates for listing under the Endangered Species Act (ESA) by the US Fish and Wildlife Service (USFWS 2010). Our 2011 study examines the effect of fire, *Bromus tectorum* (cheatgrass), herbicide use, and native grass seeding on *A. schmolliae,* and investigates demographic changes in the population.

We resampled belt transects for *A. schmolliae* that were sampled in 2001 and 2003 on Chapin Mesa. Results from 43 belt transects show a decline in density (measured in number of *A. schmolliae* individuals per square meter): 2001=0.58, 2003=0.35, 2011=0.31. A comparison of the number of individuals present in unburned vs. burned transects indicated no difference between 2001 and 2003 data (p=0.26). Results from 2003 and 2011 also indicated no difference (p=0.31). Four demography plots initially sampled in 2003 were resampled in 2011. Results indicate a decline in total individuals and a drastic decline in seedlings from 2003 to 2011. Two of the four plots showed an increase in non-reproductive individuals. A total of 82 random plots were installed to examine the effects of the following treatments: burning, herbicide use, and post-fire seeding of native grasses. Number of *A. schmolliae* individuals differed between plots that were Burned Seeded and Sprayed versus Burned Seeded Unsprayed (p=0.03). The mean number of individuals present in Burned Seeded Unsprayed plots is much higher (20.93) than in Burned Seeded Sprayed plots (8.77). No differences were found in pairwise comparisons of seeded vs. unseeded. No differences were found in cheatgrass cover between pairwise treatment comparisons.

INTRODUCTION

Resource managers attempting to conserve rare plant species are often overwhelmed by uncertainty, largely 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. *Astragalus schmolliae* is among the rarest of Colorado's endemic plant species. It is considered globally critically imperiled (G1) by the Colorado Natural Heritage Program, and has recently been added as a candidate for listing under the Endangered Species Act (USFWS 2010).

Species Information

Figure 1. *Astragalus schmolliae* in fruit.

A. schmolliae is an herbaceous perennial in the legume family. The species is characterized by its bushy appearance, white flowers, and downward curving pods (Figure 1). Its 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. It is found primarily growing in red loess on mesa tops in old growth pinyon-juniper woodlands between 6,500 and 7,500 feet in elevation. Like many rare plants, *A. schmolliae* is globally rare, but locally abundant throughout occupied habitat.

Previous Studies

The 12 month finding for *A. schmolliae* states the most significant threat to the species is the degradation of habitat by fire, followed by *Bromus tectorum* (cheatgrass) invasion, leading to an increase in fire frequency (USFWS 2010). The frequency of large, severe fires during the last ten years at MEVE clearly exceeds anything observed in the previous 100 years (Floyd et al. 2004). Although these fires may be within the range of historic variability, they have created conditions that have allowed weeds to spread through a significant portion of the range of *A. schmolliae* (Floyd et al. 2000; Floyd et al. 2004). *Bromus tectorum* invasion alters the fire regime and leads to more frequent fires, often causing degradation and fundamental changes to the ecology of native ecosystems. Fire itself may also have medium- or long-term impacts to *A. schmolliae*. Other impacts include infrastructure development, drought, and grazing by native herbivores and livestock. Between 2001 and 2003, drought appeared to have been the primary cause of mortality. *A. schmolliae* is probably well adapted to surviving and rebounding after significant drought events, although the intensification and increase in frequency of these events predicted by climate models suggest that drought may become problematic for the species in the future.

In 2001, the Colorado Natural Heritage Program began a population status survey of *A. schmolliae*, which is the most detailed investigation of this species to date. Field work was conducted in 2001 and in 2003 during which the population in MEVE was mapped, survey transects were sampled to determine density and other environmental variables, natural history observations were made, permanent plots were established to monitor demographic variables, and some basic autecological research was conducted. In 2002, it was decided to postpone fieldwork on this project until 2003 because severe drought had caused most *A. schmolliae* individuals to remain dormant. Then, from July 29 to August 4, 2002, the Long Mesa Fire burned 2,601 acres on Chapin and Park Mesas, which included 37.9% percent of the known distribution of *A. schmolliae* in MEVE. This resulted in additional concern for the viability of *A. schmolliae* and created new management challenges. It also provided a valuable opportunity to investigate the effects of fire on this species, which was addressed in 2003 using quantitative and qualitative methods.

Results Summary from 2003 Population Status Survey

A. schmolliae occupies 806.1 hectares in MEVE on Chapin Mesa, the West Chapin Spur, and Park Mesa. Of this, less than one percent burned in the 1996 Chapin 5 Fire. Later, in 2002, a total of 306 hectares of the occupied habitat burned in the Long Mesa Fire. In 2001 and 2003, population density was determined throughout the known extent of *A. schmolliae* in MEVE. The average density of *A. schmolliae* in MEVE was estimated to be 0.060 plants per square meter in 2001, and 0.037 plants per square meter in 2003. Data from transects that were resampled in 2003 suggest that population density decreased 39% from 2001 to 2003. The difference in population density between burned and unburned areas in 2003 was statistically insignificant, suggesting that fire is not responsible for the population decline. However, the sample size was small, and more rigorous sampling was needed. Drought conditions or prolonged dormancy were proposed as the most likely causes of the observed population decline.

In 2003, *A. schmolliae* seedlings were observed in burned and unburned areas throughout MEVE. However, no seedlings were documented at the population on northern Park Mesa that was burned in 1996 by the Chapin 5 Fire. Viability of seeds collected in 2003 was very high (between 94 and 100%). The patterns of seed germination are suggestive of a species that maintains a persistent seed bank. Recruitment appears to be highly episodic and is probably greatest in years that are moist in March through May. Plants in areas burned in 2002 displayed higher reproductive effort and vigor, and produced approximately 241 times more seeds per plant than did plants in unburned areas (Anderson

2004). It is possible that this resulted in part from a reallocation of pollinators from unburned areas to burned areas. Plants in areas burned in 1996 on Park Mesa had very high vigor in 2003 (possibly due to high soil nitrate levels). However, individuals on Park Mesa did not produce fruit in 2003. Following the 2002 fire, *Bromus tectorum* and *Carduus nutans* quickly invaded Chapin Mesa. In an attempt to control noxious weeds, the following herbicides have been applied using spot treatment within occupied *A. schmolliae* habitat at the head of Fewkes Canyon, as well as at the northwest end of Chapin Mesa: Curtail, Habitat, Journey, Milestone, Plateau, Roundup Pro, Telar, Transline. Park records of herbicide application show treatment dates from 1999 to 2010.

Objectives

Primary objectives for the 2011 study were as follows: 1) examine *A. schmolliae* population density and trends on Chapin Mesa by resampling belt transects installed in 2003, 2) establish random plots throughout Chapin Mesa as a pilot study to investigate the effects of fire, cheatgrass, post-fire seeding, and herbicide application, 3) relocate and resample the 2003 demography plots to investigate patterns of fecundity, vigor, and life history stages.

METHODS

Field work was conducted in 2011 during two trips: May 2nd – 10th, June 13th- 20th. A total of three different types of monitoring plots were sampled: random plots, demography plots, and belt transects.

Random Plots

We established 82 random plots among four treatment types (Table 1). We encountered difficulty establishing a balanced sample size for all treatments, due to the small size of the Burned Seeded Sprayed treatment area. No areas contained the treatment Burned Unseeded Unsprayed. Plots are scattered throughout Chapin Mesa and West Chapin Spur.

Table 1. Number of plots installed per treatment type in 2011.

TREATMENT	NUMBER OF PLOTS INSTALLED
Burned Seeded Sprayed	13
Burned Seeded Unsprayed	27
Burned Unseeded Sprayed	21
Unburned	21
Total	**82**

Several plot designs were tested in the field before determining that a 30m x 2m rectangular plot was typically large enough to contain at least one *A. schmolliae* individual. Using ArcMap, 100 random points were created within each of the four treatment areas: 1) Burned Seeded Sprayed; 2) Burned Seeded Unsprayed; 3) Burned Unseeded Sprayed; 4) Unburned. Random points were loaded onto a Trimble Geo XT provided by U.S. Fish and Wildlife Service. In the field, we navigated to each random point. Once at the random point, we used a compass to find a north bearing and walked north 30 meters from the random point, laying out a tape measure along our route. This line of tape marked the eastern side of each plot (Figure 2). Another tape measure was used to establish the western edge of the plot, which was located 2 meters west of the initial 30 meter tape line.

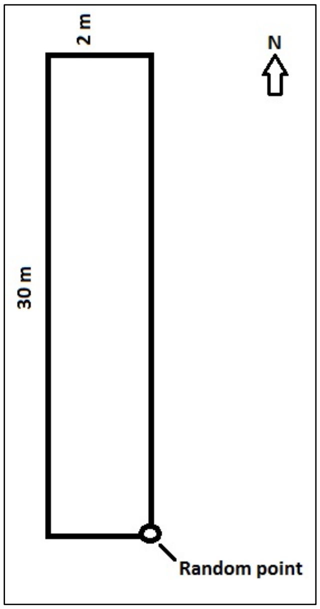

Figure 2. Layout of permanent, rectangular plots established in 2011.

The tapes were staked and all *A. schmolliae* individuals within the plot were flagged. If the plot contained *A. schmolliae* individuals, rebar was hammered into the ground at both the north and south ends of the plot and marked with a metal tag (tag number sequence is 701-783). No plots were established at random points that did not contain individuals. A photo was taken at the south end of each plot, looking north. Each of the 30 meters was split into a quadrat (Q1-Q30). Number of individuals found in each quadrat was recorded. Observations of threats were recorded including herbivory, trampling, exotic species, or frost damage. We used a point-line intercept along the 30m length of the eastern side of each plot. A pin flag was dropped along the inside edge of the measuring tape at half meter intervals (60 total hits). Categories for hits were *Achnatherum hymenoides*, *Bromus inermis, Bromus tectorum, Carduus nutans*, *Elymus elymoides*, *Erodium cicutarium*, *Pascopyrum smithii*, *Poa fendleriana*, *Verbascum thapsus*, Litter, or Bare Ground. Finally, a point was taken at both north and south ends of the plot with a Trimble GEO XT or a Garmin GPS. Plots were established in all of the treatment areas (Table 1).

The total number of *A. schmolliae* individuals per plot was non-normally distributed, so we used non-parametric, two-sample Wilcoxon rank-sum tests (alternative hypothesis=two-sided, test type=exact) to compare pairwise treatment types. To compare cover of key species between different treatments, we used a paired sample Wilcoxon test (alternative hypothesis=two-sided, test type=exact). All statistical tests for these data and the data below were performed using R 2.13.2.

Demography Plots

We were able to relocate the four demography plots that were established in 2003. However, difficulty relocating the Park Mesa plot led to a slight shift in plot location. Methods for sampling the demography plots follow those described in Anderson 2004. Plots were 10m x 10m, and divided into four quadrants. Each quadrant measured 5m x 5m. Each *A. schmolliae* individual within the entire plot was marked with a pin flag. Individuals were assigned a life history stage (Seedling, Non-Reproductive, and Reproductive). Reproductive effort and vigor were assessed nondestructively using the methods of Floyd-Hanna et al. (1999) on all marked adults at all plots. Reproductive effort was assessed by counting flowers, fruits, and aborted flowers on each marked adult. Vigor was assessed by counting the number of stems per plant. Since previous sampling efforts did not follow marked individuals, we were not able to use regression techniques or modeling to analyze data. Additionally, sample size was too small to perform statistical tests. Instead, bar charts were created in Excel to show population trends.

Belt Transects

A total of 43 belt transects covering 4,067 meters were sampled by Anderson in 2001 and 2003 to assess the density of *A. schmolliae* on Chapin Mesa. All were resampled in June 2011. Each transect is oriented in an east-west direction, traversing Chapin Mesa. The transects were 10 meters wide and spaced 500 meters apart following UTM northing lines projected in NAD 27 Datum, Zone 12T. Each belt transect was broken into 100m x 10m segments. Within each segment a census of the *A. schmolliae* individuals was recorded. To avoid deviating from the UTM northing line, we used a Garmin GPS and compass. To analyze data, we calculated the change from 2001 to 2003, and from 2003 to 2011. In ArcMap 10, we created density grids that were interpolated from belt transect data using Kernel Density and a 500 meter search radius. We also used the resulting differences to test for a difference between burned and unburned transects using two-sample Wilcoxon rank sum tests (alternative hypothesis=two-sided, test type=exact).

RESULTS

Random Plots

The total number of *A. schmolliae* individuals present in each plot was non-normally distributed, and the highest mean was found in the Burned Seeded Unsprayed plots (20.92), and the lowest in the Unburned plots (8.19) (Figure 3; Table 2).

The following pairwise treatments were compared to analyze the effects of spraying and seeding, and are herein referred to by Pairwise Treatment Number: 1) Burned Seeded Sprayed and Burned Seeded Unsprayed, 2) Burned Seeded Sprayed and Burned Unseeded Sprayed, and 3) Burned Seeded Unsprayed and Burned Unseeded Sprayed (Table 2). Unburned treatment comparisons were not performed due to lack of plots that were burned with no other treatments. Results from two-sample Wilcoxon rank-sum tests showed significant differences for number of *A. schmolliae* individuals in only one treatment comparison (Table 2). At an $\alpha=0.05$ level, there was a significant difference between the number of *A. schmolliae* individuals in Pair 1 ($p=0.03$, $n=40$, $W=112$). Number of individuals did not differ between treatments in Pair 2 ($p=0.38$, $n=34$). Furthermore, plots in the Burned Seeded Unsprayed did not differ from the Burned Unseeded Sprayed ($p=0.16$, $n=48$, $W=351$). Differences in Unburned plots were not tested, as there were no plots that were simply burned, with no spraying or seeding.

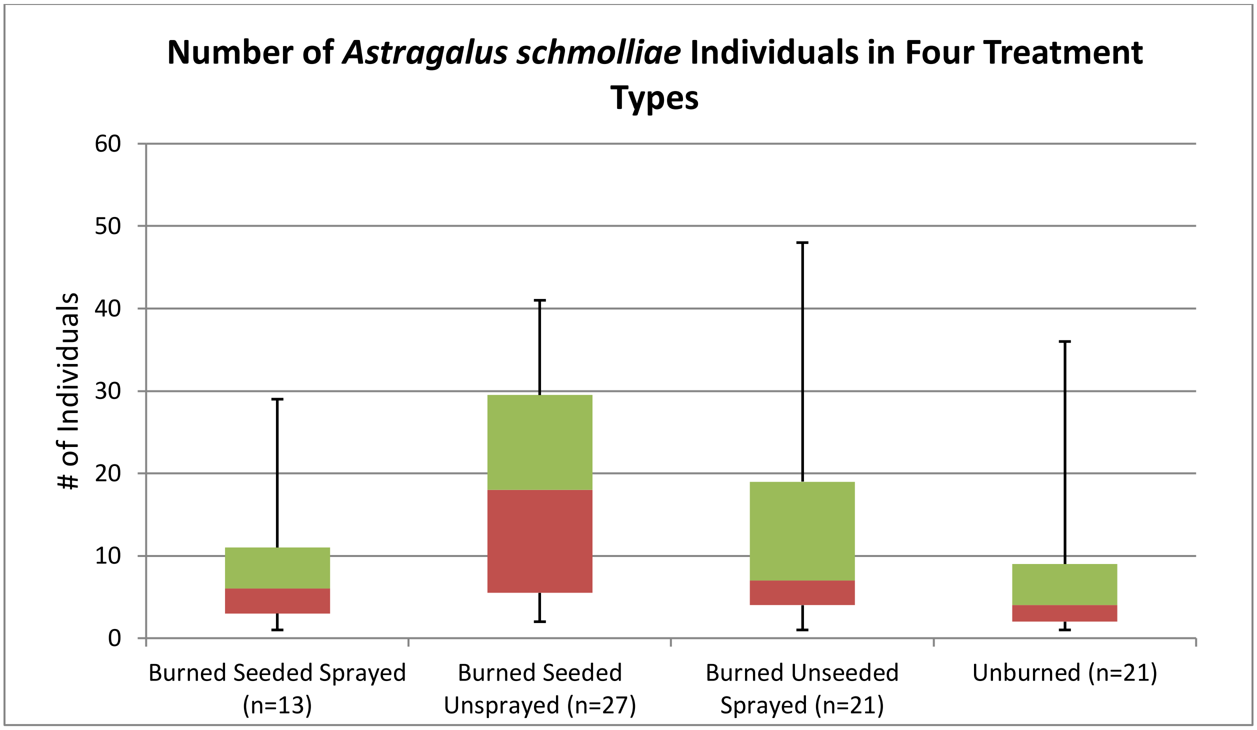

Figure 3. Number of *Astragalus schmolliae* individuals present in each plot, by treatment type.

Table 2. Results of two-sample Wilcoxon rank sum tests (alternative hypothesis=two-sided, test type=exact) comparing number of *Astragalus schmolliae* individuals present in plots with different treatment types.

Treatments tested	Pairwise Treatment Number	Number of Plots (N)	Mean number of individuals	Median number of individuals (Q1, Q3)	Standard deviation	p value (Wilcoxon rank sum test)
Burned Seeded Sprayed	1	13	8.77	6 (3,11)	8.02	0.03
Burned Seeded Unsprayed		27	20.93	18 (5.5, 29.5)	19.68	
Burned Seeded Sprayed	2	13	8.77	6 (3,11)	8.02	0.38
Burned Unseeded Sprayed		21	14.14	6 (4, 19)	14.47	
Burned Seeded Unsprayed	3	27	20.93	18 (5.5, 29.5)	19.68	0.16
Burned Unseeded Sprayed		21	14.14	6 (4, 19)	14.47	

Cover values of key species revealed no *Bromus tectorum* (cheatgrass) cover in any unburned plots (Figure 4). Paired sample Wilcoxon tests revealed no differences, however, in *B. tectorum* cover for all three pairwise treatments at an α=0.05 level (Table 3). Furthermore, no differences were found in *Poa fendleriana* (muttongrass) cover except in Pair 3 (p=0.04). All other key species had cover values below 0.01, so were not tested for significance. Bare ground and litter were not sampled for 30 plots, so sample sizes among treatments were not large enough to perform paired sample Wilcoxon tests.

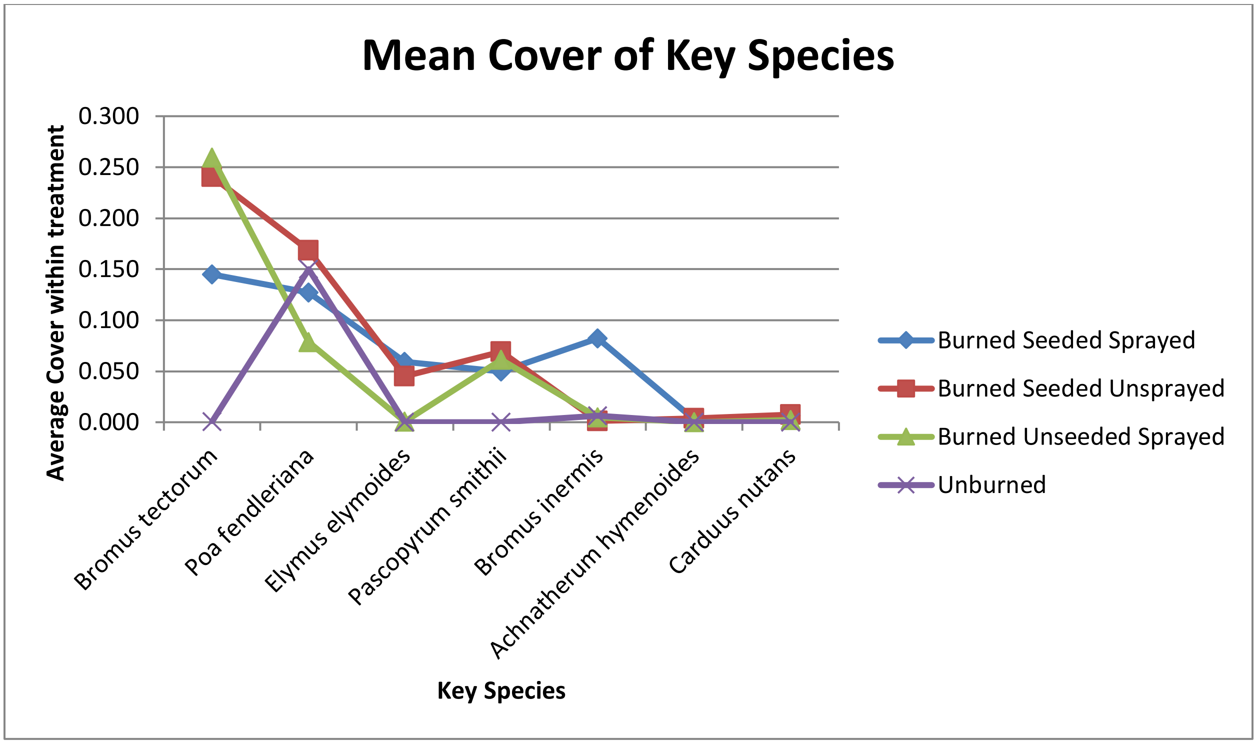

Figure 4. Mean cover of key species in four treatment types. Bare ground and litter were eliminated from results, as only 52 total plots were sampled for these categories.

Table 3. Results of a paired sample Wilcoxon test (alternative hypothesis=two-sided, test type=exact) comparing *Bromus tectorum* (cheatgrass) cover and *Poa fendleriana* (muttongrass) cover between plots with different treatment types.

Treatments tested	Pairwise Treatment Number	Number of Plots (N)	*Bromus tectorum* V value, p value	*Poa fendleriana* V value, p value
Burned Seeded Sprayed	1	13	V=33.5, p=0.42	V=34, p=0.46
Burned Seeded Unsprayed		27		
Burned Seeded Sprayed	2	13	V=20.5, P=0.16	V=37, p=0.76
Burned Unseeded Sprayed		21		
Burned Seeded Unsprayed	3	27	V=107.5, P=0.79	V=147 P=0.04
Burned Unseeded Sprayed		21		

Demography Plots

Life History Stages

Total number of seedlings present at West Chapin Spur, Sun Point, and Sun Temple dramatically decreased from 2003 to 2011 by the following percentages (98.4%, 95.1%, 92.9%, respectively) (Figure 5). The Park Mesa demography plot was not sampled for life history stages in 2003, but 80 total seedlings were counted in 2011.

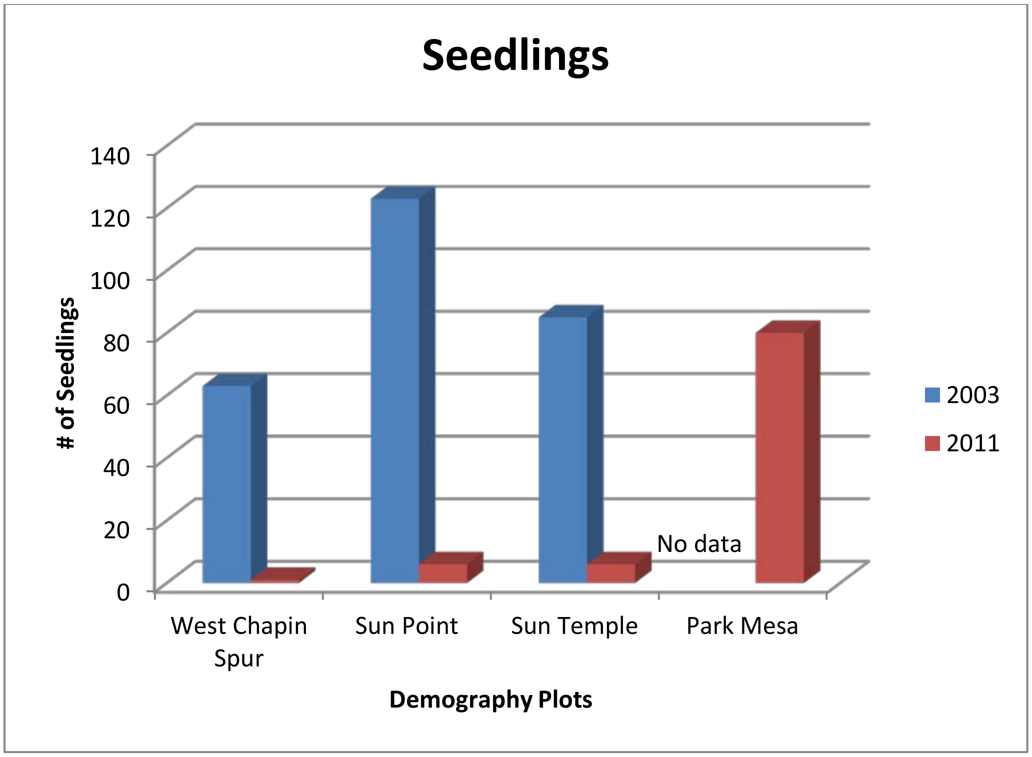

Figure 5. Total number of *A. schmolliae* seedlings present in three demography plots. Seedlings are defined by presence of cotyledons and lack of dried stems from previous years' growth. West Chapin Spur and Sun Temple burned in the 2002 fire. Sun Point is unburned.

Total number of non-reproductive individuals present at West Chapin Spur, Sun Point, and Sun Temple increased from 2003 to 2011 by the following percentages (170.0%, 100.0%, 16.5%, respectively) (Figure 6). At the Park Mesa, 80 total juveniles were counted in 2011.

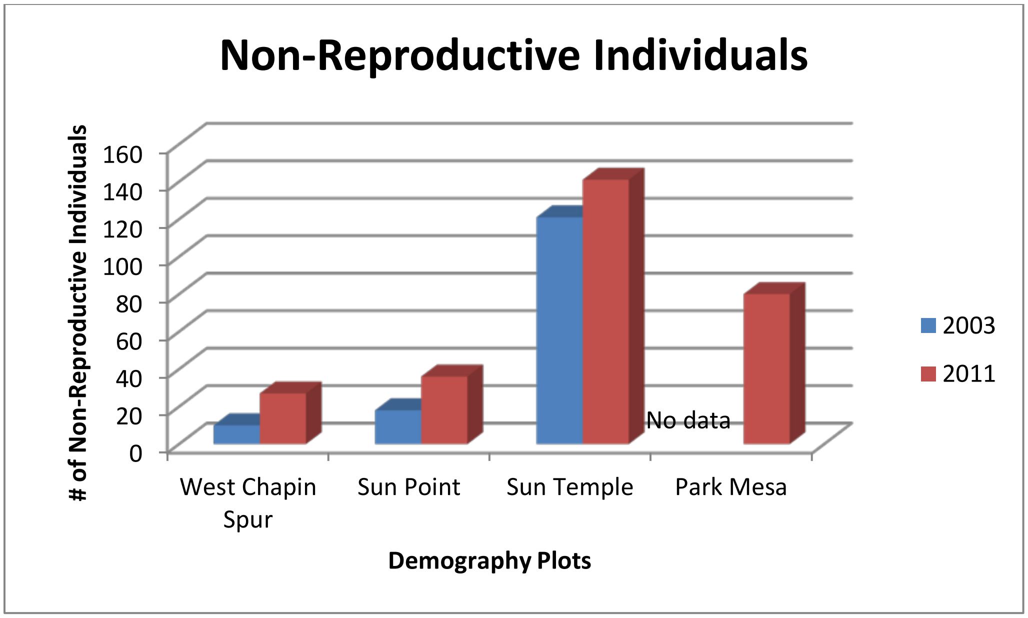

Figure 6. Total number of *A. schmolliae* non-reproductive individuals present in three demography plots. Non-reproductive individuals are characterized by the presence of last year's dried stems, and lack of flowers or fruits. West Chapin Spur and Sun Temple burned in the 2002 fire. Sun Point is unburned.

Total number of reproductive individuals present at West Chapin Spur, Sun Point, and Sun Temple decreased from 2003 to 2011 by the following percentages (33.3%, 92.9%, 2.2%, respectively) (Figure 7). At the Park Mesa, 16 total reproductive individuals were counted in 2011.

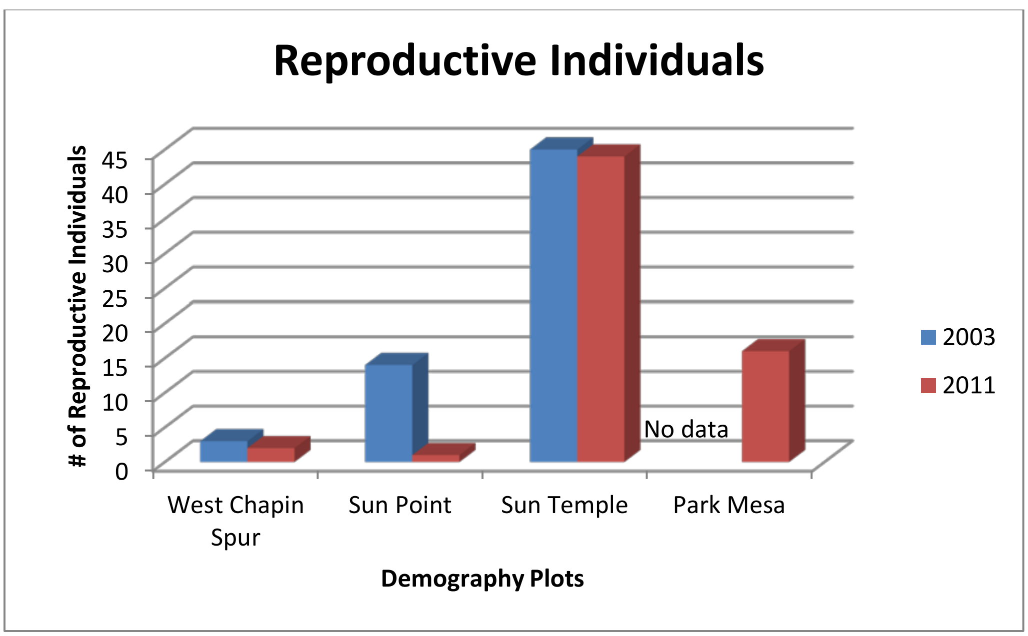

Figure 7. Total number of *A. schmolliae* reproductive individuals present in three demography plots. Reproductive individuals have flowers and/or fruits. West Chapin Spur and Sun Temple burned in the 2002 fire. Sun Point is unburned.

Vigor

Vigor, or total number of stems per individual, was measured at Sun Point, Sun Temple, and Park Mesa for 2003 and 2011 (Figure 8). At Sun Point, vigor decreased (1.30 to 1.27). Vigor increased at Sun Temple (1.96 to 4.1), and decreased at Park Mesa (10.06 to 6.86). Mean vigor at the West Chapin Spur plot was 5.93 in 2011, but was not sampled in 2003.

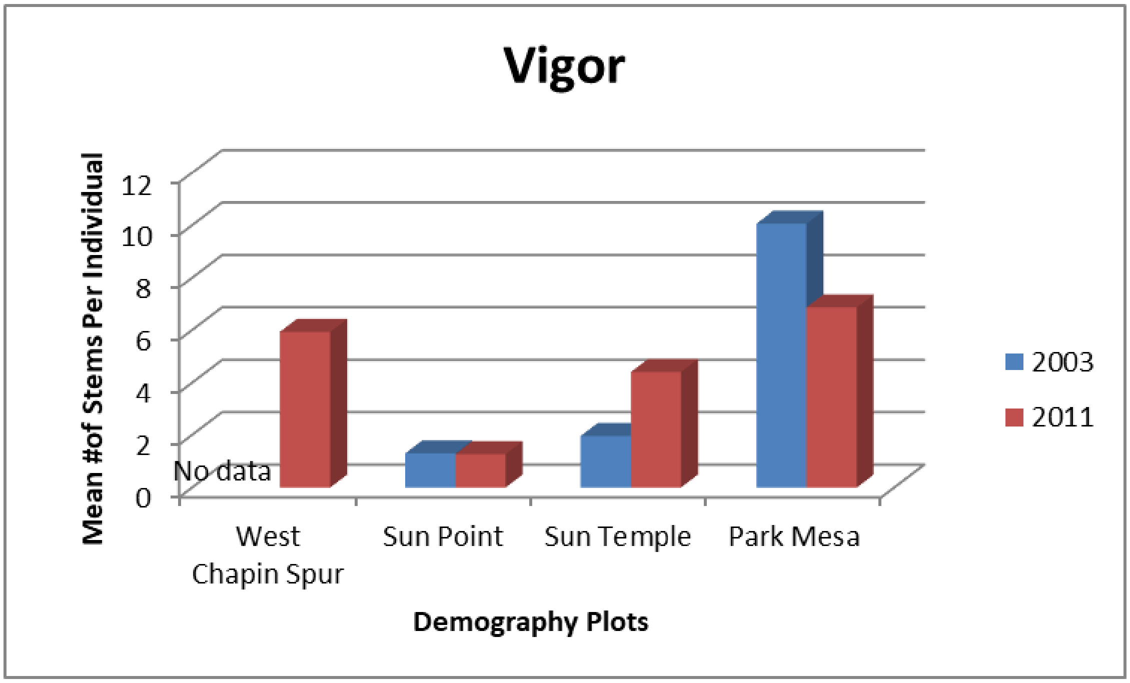

Figure 8. Mean number of stems in three demography plots. Sun Temple and Park Mesa burned in different years (2002 and 1996, respectively). Sun Point is unburned.

Reproductive Effort

Total flower and fruit production per plot decreased at Sun Point and Park Mesa, and increased at Sun Temple (Table 4). The large numbers of aborted flowers observed likely were due to frost damage in early May.

Table 4. Total number of flowers, fruits, and aborted flowers present at four demography plots. West Chapin Spur was not sampled in 2003.

Demography Plot	# of Flowers		# of Fruits		# of Aborted Flowers	
	2003	**2011**	**2003**	**2011**	**2003**	**2011**
West Chapin Spur	--	0	--	0	--	88
Sun Point	391	0	3	0	303	0
Sun Temple	562	1	648	0	856	2627
Park Mesa	801	0	0	0	48	610
Total	***1753***	***0***	***651***	***0***	***1207***	***3325***

Belt Transects

Density, or the number of individuals per m², was determined by resampling 43 belt transect segments on Chapin Mesa that were sampled in 2001 and 2003. Results show an overall decline in density: 2001=0.58, 2003=0.35, 2011=0.31 (Figure 9). Density grids indicate a decrease across the northern transect from 2001 to 2003, while the southern transects show the sharpest declines in the unburned SW corner of Chapin Mesa. From 2003 to 2011, density decreased along most of the northern transect, and the. southern transects revealed more complex changes in density, with the largest increases in burned, seeded, unsprayed areas, and largest decreases in the unburned areas.

Statistical analysis using two-sample Wilcoxon rank sum tests (alternative hypothesis=two-sided, test type=exact) were conducted comparing number of individuals present in burned vs. unburned transects. Results from 2001 to 2003, at an $\alpha=0.05$ level, indicate no difference ($W=161.5$, $p=0.26$). Results from 2003 and 2011, also indicated no difference ($W=112$, $p=0.31$).

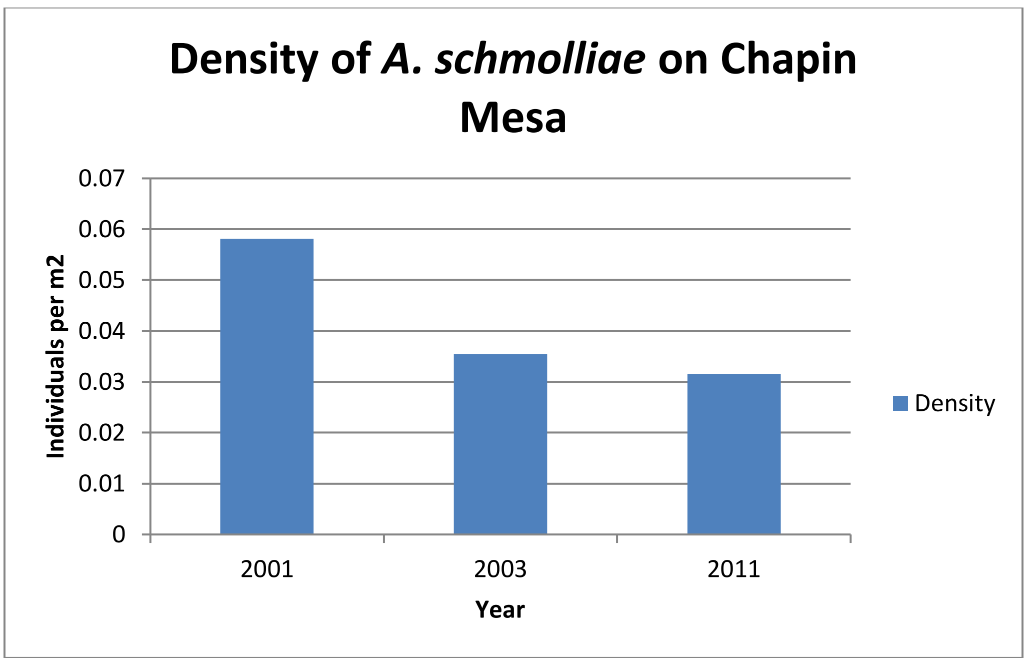

Figure 9. Mean density of *A. schmolliae* individuals present in belt transects from 2001-2011.

DISCUSSION

Post-fire seeding and herbicide spraying have led to complex vegetation patterns at Chapin Mesa. In 2011, our pilot study attempted to analyze the effects of these treatments on *A. schmolliae*. Mean number of individuals was highest in plots that were Burned Seeded Sprayed, and lowest in Unburned plots. These results, which suggest that *A. schmolliae* is adapted to, or at least tolerant of, a natural fire regime, are congruous with observations made by Anderson (2004) and Floyd et al (1999). However, we were not able to test for differences between number of individuals in unburned plots against burned plots, as all plots that were burned had been seeded and/or sprayed. Cover of *Poa fendleriana* (muttongrass) was different between Burned Seeded Unsprayed plots and Burned Unseeded Sprayed plots, with mean cover values of 0.17 and 0.08, respectively. This suggests that post-fire seeding of *P. fendleriana* has been somewhat successful. Cover of *Bromus tectorum* (cheatgrass) did not differ between treatment types, and was not present in the Unburned plots. Noxious weed cover, including *Carduus nutans* (musk thistle), was difficult to detect using our point line intercept method. Cover values were very low for all noxious weeds and the seeded grass species *Achnatherum hymenoides*, *Elymus elymoides*, and *Pascopyrum smithii,* and thus were not analyzed using any statistical tests. Bare ground and litter were not analyzed, as data for these categories was not collected on 30 of the 82 plots.

A pattern of decline in density of *A. schmolliae* was observed, but decline from 2003 to 2011 was less dramatic (-0.04 individuals per square meter) than from 2001 to 2003 (-0.23 individuals per square meter). No differences from 2001-2003 and 2003-2011 were found between burned and unburned sections of transects on Chapin Mesa.

Seedlings and adults present in demography plots indicate a pattern of decline, while juveniles have increased. Vigor and flower and fruit production show complex patterns, and may be influenced by precipitation and temperature. Frost damage was observed as the main contributor to aborted flowers in 2011. However, sample size, sampling effort (only two years of data), and no marked individuals make patterns of survivorship, age, and recruitment impossible to discern.

Future research should include re-sampling the belt transects for a fourth year, to further investigate density decline. Transects in the central part of Chapin Mesa that were only sampled in 2001 should be sampled in future years, as portions of these have been sprayed with herbicide. We recommend a study investigating the effect of herbicide spraying on *A. schmolliae* (such as Transline, Round-up Pro, and Milestone), based on the results of our random plots. The following life history questions remain unanswered for the species: 1) How long-lived is the species? 2) What are the main floral visitors and effective pollinators? 3) Does wild horse trampling increase or decrease numbers of individuals? The demography plots in this report were set-up with limited time and funding. In order to better understand the life history of *A. schmolliae*, we recommend a long-term demographic study following marked individuals.

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