Initial Response of *Arabis johnstonii* Munz to Fire

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ABSTRACT. *Arabis johnstonii* Munz (Johnston's rock cress) is a small herbaceous perennial plant endemic to the San Jacinto Mountains of southern California. It is considered rare by the California Native Plant Society and is a Forest Service Sensitive species. Three *A. johnstonii* occurrences grow within an area that the San Bernardino National Forest plans to burn for hazardous fuel reduction. Prior to this study little was known about fire effects on *A. johnstonii*. We used a 1.1 m diameter cylindrical stainless steel wire "fire cage" within which we conducted small-scale experimental burns on twenty clusters of *A. johnstonii*. Weather, fuel conditions, and fire behavior were recorded during burns conducted in September 2003 and January 2004. *A. johnstonii* survival, growth and recruitment will be measured twice a year for up to three years after the fires. About five months after the first experimental burn, most *A. johnstonii* were still alive, but they were generally smaller and shorter than unburned individuals. Burned *A. johnstonii* showed no change in numbers of individuals compared to pre-burn counts, however unburned plot numbers increased by 15 percent over the same time period.

INTRODUCTION

Hazardous conditions persist in many areas of the Southwest as decades of fire suppression now coalesce with drought to produce dangerous accumulations of flammable fuels. The firestorms that burned southern California during 2003 vividly illustrate how wildland areas, now intertwined with urban sprawl, create perilous zones of extreme fire risk. Land managers labor to reduce fuels for both ecosystem health and human safety. Ironically, prescription burning may be the tool that could most effectively reduce fuel and thus fire danger over relatively large areas. The trick is to apply it under thoughtfully prescribed and operationally safe conditions.

Even when conditions are appropriate, the presence of rare species may complicate attempts to implement any desirable fuels treatments, prescribed burning included. Resource managers hesitate to place a rare species or its habitat in jeopardy when nothing is known about how the disturbance will affect it (e.g. when positive or negative fire effects are unknown for a species of concern). But failure to treat accumulated fuels could lead to habitat disturbance by wildfire, with equally unknown impacts. Prescribed burns can be accomplished with complex boundaries designed to exclude rare species. However, some rare species benefit from fire and would then be excluded from this positive management practice. Obviously, information is urgently needed to resolve this predicament without exposing already vulnerable populations to harmful perturbation or to chance.

Arabis johnstonii Munz (Johnston's rock cress), a small herbaceous perennial in the mustard family (Brassicaceae), occurs in the San Jacinto Mountains of western Riverside County, California (California Native Plant Society 2001, Rollins 1993) (Fig. 1). *A. johnstonii* is a Forest Service Sensitive species and is listed as rare by the California Native Plant Society (California Native Plant Society 2001). *A. johnstonii* grows on various soil types near Garner Valley within the San Bernardino National Forest (SBNF) (Berg and Krantz 1982, California Natural Diversity Database 2001). The SBNF wants to use prescribed fire in Garner Valley and vicinity for fuel hazard reduction to protect nearby mountain communities. A prescribed fire was conducted in the general area in the early 1980s, but no specific information was collected on whether any *A. johnstonii* actually were burned at that time. No historic fire effects data exist for the locations within the proposed prescribed fire perimeter where three *A. johnstonii* occurrences grow. No fire effects have been documented for *A. johnstonii* at other sites either.

FIGURE 1--*Arabis johnstonii* (Johnston's rock cress) in bloom on the pebble plain-like soil at McGregor Flat, San Jacinto Mountains, California in April 2004.

Fire, prescribed or accidental, and related activities harbor many challenges and could have possible unknown consequences for tenuous species or populations such as *A. johnstonii*. Multiple fuel breaks would have to be built within the proposed burn to isolate the three populations. Site disturbance for fuel break construction could incidentally harm some *A. johnstonii* or promote invasion by nonnative plants. The consequences of such perturbation could be worse for the species than impacts from fire itself. Prescribed burning may promote open tree and shrub canopies where these plants occur. Total fire exclusion may allow canopy closure, which may have negative consequences for this plant.

Overriding concerns about escalating fire hazard evolving from an extended drought and accumulating dead fuels were paramount in the decision to risk the injury or sacrifice of a limited number of *A. johnstonii*. Information obtained for another rare California *Arabis* species suggests that fire would not unduly harm *A. johnstonii*. *Arabis* Shockleyi Munz., (Shockley's rock cress) growing on the Angeles National Forest, survived the Williams Fire in 2002. *A. johnstonii* has similar growth habits, with basal leaves, tuberous root and aboveground parts that may undergo drought or summer dormancy, and growing in openings in chaparral where fire may burn less intensely. These characteristics suggest that *A. johnstonii* may survive fire given the appropriate fire weather conditions (SBNF botanist M.A. Lardner, personal communication).

In southern California, safe prescribed or controlled burning must occur during narrow windows of opportunity when fuel and weather conditions allow optimal fire safety and containment. These conditions typically occur during winter and spring when fuel moisture is high and there is little chance for fire to escape. The impacts of out-of-season prescribed fire can be different from those of summer fire (reviewed in Beyers and Wakeman 2000), adding further complication to the job of prescribing fire in rare plant habitat. Summer or fall may be an ecologically more appropriate time to burn because many species have passed their peak growth periods and reproductively vulnerable stages. At this time, vegetation may naturally ignite from lightning strikes during mountain thunderstorms

Because fuel reduction is needed in Garner Valley, the SBNF decided that small field trials would be an appropriate risk for this situation: sacrifice a few plants rather than risk decimation of the entire population to wildfire. Consequently, we designed an experiment to test the simulated effects of fire on a limited number of individual *A. johnstonii*. The study compares fire applied during the historic fire season – late summer – to fire applied in winter, when prescribed fire would normally be used. By evaluating plants burned in both seasons, we hope to determine the general response of *A. johnstonii* to fire, as well as its reaction to fire applied outside the "normal" burning window. Fire effects are currently being monitored and evaluated for *A. johnstonii* after two seasons of burning. Initial evidence shows that individual *A. johnstonii* survived and will reproduce after a September fire.

Study Sites

The three *A. johnstonii* occurrences in Garner Valley that could be affected by the proposed fuel reduction program grow among varying fuel types. These include several plant associations: 1) pebble plain-like with chaparral, 2) open sage/chaparral, and 3) logged yellow pine forest. Although all sites have 10 percent slope or less, they differ in exposure and topographic position. Site 1, near McGregor Flat (hereafter "McGregor"), is located on and near the crest of a slope at an elevation of nearly 2,200 m. Vegetation at the site is composed of chaparral, including species of *Adenostoma*, *Ceanothus*, *Arctostaphylos*, and *Quercus*. At this site, sizeable inter-shrub spaces have high clay/gravel/rock soil components that limit herbaceous fuels. *A. johnstonii* is found scattered in and around the chaparral shrubs, along a dirt access road, and near a water catchment basin used for livestock. Plants grow in full sun and in shade under shrub canopies. Livestock and rabbit grazing activity is high in this area. Fire would burn hot in clusters of chaparral fuels but probably would not carry in inter-shrub spaces because of absence of fuels.

Sites 2 and 3 are located at about 1,200 m in elevation. Site 2, near Kenworthy Station (hereafter "Kenworthy"), faces west, while Site 3, near Quinn Flat (hereafter "Quinn), faces northwest. At both sites *A. johnstonii* grows in rocky areas on slopes under and around mature *Pinus jeffreyi* Grev. & Balf. (Jeffrey pine) with various amounts of herbaceous and pine litter. The pines that formerly shaded Kenworthy died and were recently logged to reduce fire hazard. Quinn has a mixture of *Artemisia tridentata* Nutt. (big sagebrush), *Adenostoma fasciculatum* Hook & Arn. (chamise), and a few *P. jeffreyi* unevenly scattered across the slope. During certain times of the year sufficient fine fuels are available at Kenworthy and Quinn to carry fire.

There were two other rare plant species growing at Quinn: *Penstemon californicus* [Munz & I.M. Johnston] Keck (California penstemon) and *Calochortus palmeri* S. Watson var. *munzii* F. Ownbey (Munz's mariposa lily). Because no fire effects information is available for these species, they were incorporated into our burn trials. The higher elevation McGregor site had fewer and smaller *A. johnstonii* individuals than the others. Quinn appeared to have more favorable growing conditions, based on the higher *A. johnstonii* population density, greater plant size and increased diversity (Beyers et al. 2004). *Penstemon californicus* and *C. palmeri* grow later in the year than *A. johnstonii*. Therefore, from the September 2003 burns only fire effects data for *A. johnstonii* was available in winter, and data for it alone will be presented here.

METHODS

At each study site, twelve 1-m^2 areas supporting at least five *A. johnstonii* were identified as our study plots. An extra plot was established at Quinn Flat to obtain a larger sample of *P. californicus* and *C. palmeri* var. *munzii*. Each plot was mapped, permanently marked and photographed. Within each plot, all plants of the three study species were mapped and measured (height, two canopy diameters, and phenological attributes – number of flowers, stalks and seed pods). We established 37 plots with a total 382 *A. johnstonii*, 52 *P. californicus*, and 66 *C. palmeri* var. *munzii* observed during pre-burn counts.

To conduct small scale burns with realistic fire intensity and severity of effects, we constructed a capped cylindrical "fire cage" (1.1 m diameter x 0.62 m tall) using 8x8 mesh stainless steel woven wire cloth to use as a firewall to contain the flames during burns (Beyers et al. 2004) (Fig. 2). The fire cage was large enough to cover a 1 m^2 plot with a 10 cm buffer around the edges. Testing of the fire cage in a burn building allowed us to determine how well the cage worked to contain the fire, sparks and fire brands. We also determined how much and what type of fuel was needed for appropriate fire behavior, heat transfer and cooling (Beyers et. al. 2004).

Burning treatments were conducted on September 4, 2003 to imitate a "normal" summer season fire, and late January 22, 2004, to simulate a typical winter prescribed fire. Burn treatments were randomly assigned to 6 plots per site (3 each for September and January), and were paired with 3 grazed and 3 ungrazed control plots. The entire *A. johnstonii* population at Quinn is fenced from grazing so does not have an ungrazed treatment. This allowed us to burn an additional plot on each burn day.

Each burn plot was instrumented with

FIGURE 2--Operational 1 m^2 fire-cage burn of *Arabis johnstonii* conducted during January 2004 at Quinn Flat, San Jacinto Mountains, California.

two thermocouples attached to a digital thermometer: one was at the soil surface, with the other 2 cm or more below the soil surface. In addition, three ceramic tiles treated with temperature sensitive Omega-marker crayons (with maximum melting temperatures of 93, 149, 260 and 399°C) were randomly placed within each plot. Natural fuel was so sparse on most of the plots at the time we conducted the experiment that fuels would not burn sufficiently to carry fire or increase below ground temperatures at the plant root zone. For a successful heat and combustion treatment, 1 kg of pre-weighed excelsior (0.5 kg) and chaparral (0.5 kg) fuels were added to each burn plot at all three sites. A scratch line to inorganic soil and fire shelters were placed around the fire cage to serve as a fuel break. Bricks supported the fire cage above the ground so that a butane torch could be used to ignite fuels. A Forest Service fire engine and crew were on site during all ignitions.

Weather, fuel and soil moisture, and fire behavior variables were recorded prior to and during burns. Three soil and three fuel samples were collected at each site. These samples were later weighed and dried at the laboratory to determine percent moisture. The random placement of thermocouples and thermal tiles were mapped. Tiles were individually labeled and placed with half of the tile above and the other half under ground (at least 2 cm). Ignition time for each plot took about 30 seconds. Active flame duration was about 2 to 3 minutes. The thermal pulse into the soil was monitored until the soil temperature began to decrease, which was generally within 30 minutes after ignition.

Survival, growth, and recruitment of *A. johnstonii*, *P. californicus* and *C. palmeri* will be measured twice a year for three years. In this paper, we report only the effects of the September 4, 2003 burns on *A. johnstonii* because of its earlier emergence, growth and reproduction.

RESULTS

The data reported here were obtained from the burns conducted on September 4, 2003 at all three sites. Air temperatures ranged between 23 and 29°C (74 and 84°F) during the burns. Relative humidity was appropriate for burning until a storm blew in. The storm front brought rain and sleet and interrupted our last two burns at Quinn. Maximum wind speed (gusts) varied between 1 and 12 miles per hour and changed directions over the course of the day. Fire behavior varied among plots with maximum flame height ranging between 1.3 and 2.2 m with an average height of 1.8 m. During the burns, flame angles varied with the wind--maximum flame angles on plots ranged between 25 and 45 degrees. Burning of the fuels within the fire cage took about 3 minutes and averaged 95 percent combustion for all trials (table 1).

Prefire fuel and soil moisture varied among plots and sites (Fig. 3). Thermocouple depth varied by 3 cm among all plots. Temperature profiles showed peaks within the first 5 minutes

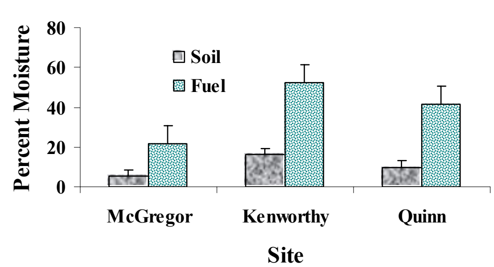


FIGURE 3 Average percent moisture content for on-site soils and fuels at study sites prior to the September 4, 2003 burns. Error bars are the standard error of the means. N=27 for fuel & soil.

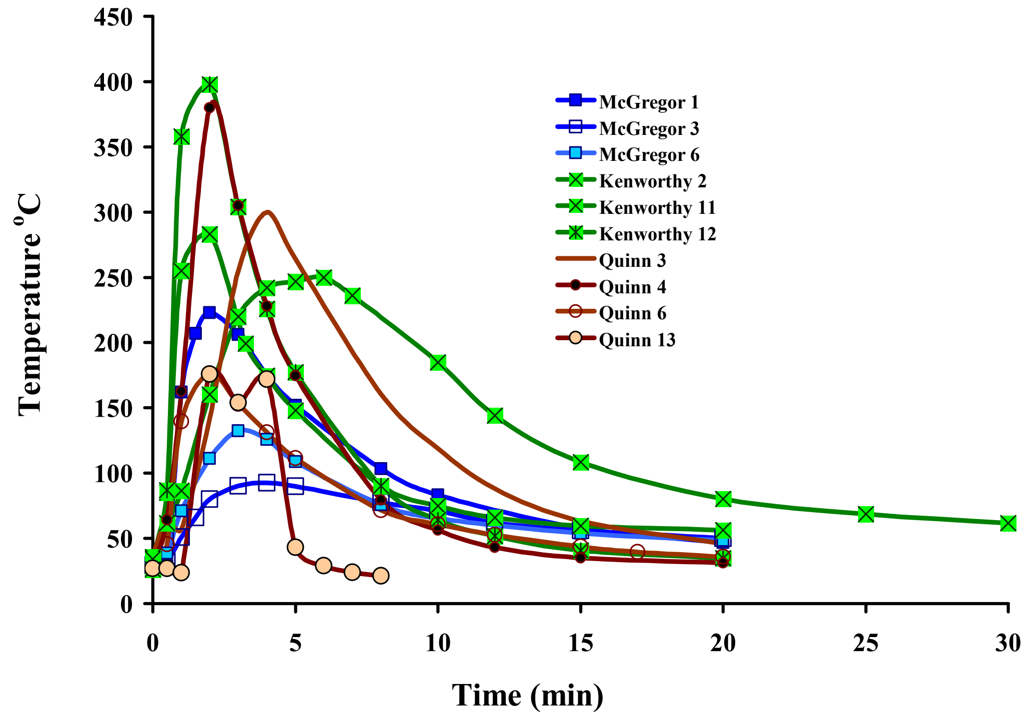
TABLE 1--Abiotic conditions recorded during experimental burns conducted September 4, 2003, at the three study sites on the San Bernardino National Forest, San Jacinto, California.

Site	Plot #	Air °C	RH %	Wind mph	NSEW	Fuel % consumed	Flame height m	[a]Flame < degrees	[b]T1 depth cm
McGregor	1	27	48	7	N	98	1.5	30	2.2
	3	29	36	3.6	NE	98	2.2	45	3.7
	6	27	36	6.9	NE	95	1.5	30	4.2
Kenworthy	2	31	49	7.9	SE	99	2	25	5.4
	11	31	38	2.7	SE	92	1.3	30	3.2
	12	27	49	3	S	98	2.0	30	3
Quinn	3	29	44	8.3	SE	95	1.7	45	4.6
	4	24	65	12	SSW	95	1.7	45	4.5
	6	23	58	7	NW	95	2.0	45	3.2
	13	24	100	1.5	N	85	1.5	30	5.2

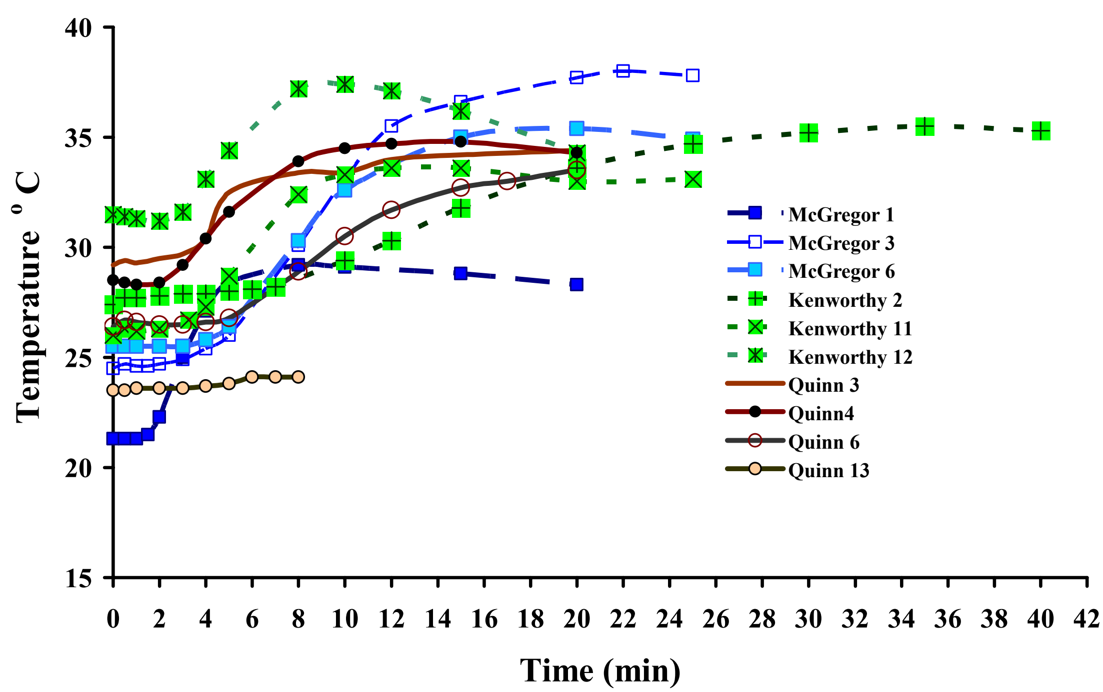
[a] Flame angle (<) in degrees
[b]T1=buried thermocouple

after ignition (Fig. 4a). Maximum temperatures reached 400°C on the soil surface and were highly variable among plots. Below ground temperatures remained below 40°C (Fig. 4b). The thermal crayon tiles did not show any change below ground. However, most tiles registered increased temperatures above ground throughout each plot. The lowest tile temperature of 93°C was reached on all (26) except two tiles at the McGregor site. Twenty-two tiles registered temperatures between 149 and 260°C; only one tile from Quinn, two from McGregor, and three from Kenworthy did not reach these temperatures. Seven tiles (four at McGregor and three at Quinn) reached temperatures between 260 and 399°C. One tile at the Quinn site reached a temperature of over 400°C

Pre-burn counts of *A. johnstonii* varied among plots and sites. Quinn had the most individuals per plot overall, while McGregor had the least (Fig. 5). Data collected in January after the September burn show that post-fire *A. johnstonii* populations were similar to pre-burn counts (Table 2). However, over this same period of time the unburned plots increased in plant abundance (table 2). Overall, the average number of plants found per square meter was slightly lower in the burned compared to the unburned plots for all sites (Fig. 6). Post-fire mean plant heights were less than in unburned plots (Fig. 7). The average cover for burned plots was only about one third (12.8 cm^2) of the cover observed in unburned plots (31.4 cm^2) (Fig. 8). At this time, results have not been tested for significance.



a.



b.

FIGURE 4a & b Fire temperature profiles recorded by thermocouples above (a) and below (b) ground at the three study sites during the September 4, 2003 burns.

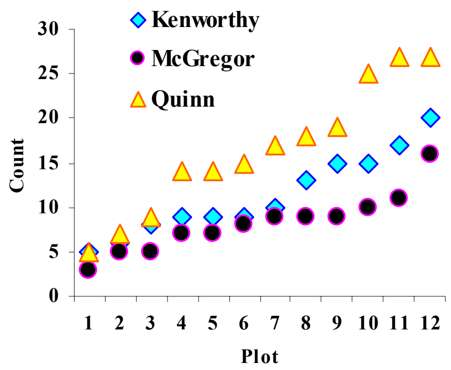


FIGURE 5 -Number of *Arabis johnstonii* plants per plot recorded in pre-burn counts at three study sites on the San Bernardino National Forest, California.

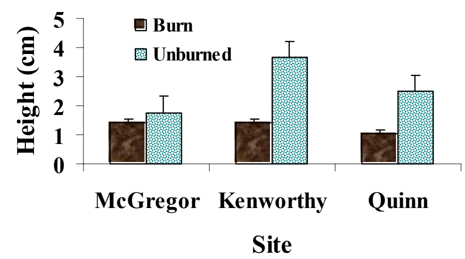


FIGURE 7 Average height of *Arabis johnstonii* plants in burned and control plots recorded 4.5 months after the September 2003 burns on the San Bernardino National Forest, California. Height of unburned plants included dead flower stalks from the previous year; all flower stalks burned in treated plots. Error bars represent standard error of mean.

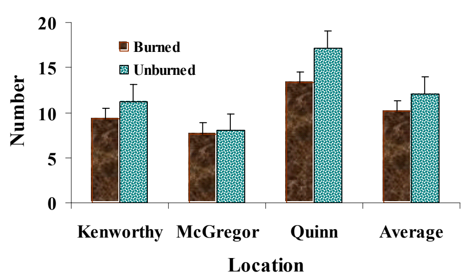


Figure 6 Average number of *A. johnstonii* plants per square meter recorded January 22, 2004 at each study site on the San Bernardino National Forest, CA. Error bars represent standard error of mean.

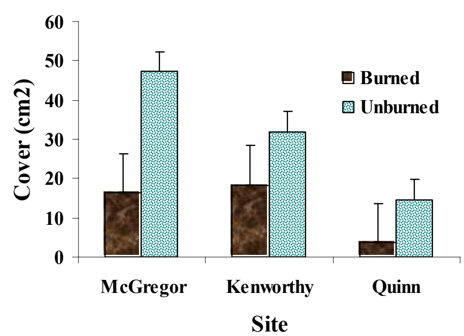


FIGURE 8 **A**verage cover of *Arabis johnstonii* plants in burned and unburned plots 4.5 months after the September 2004 burns. Error bars represent standard error of mean.

TABLE 2 Total number of *Arabis johnstonii* plants recorded within all plots at each site before (Pre) and 4.5 months after (Post) the September 04, 2003 experimental burns on the San Bernardino National Forest, California.

	Kenworthy		McGregor		Quinn	
Treatment	Pre	Post	Pre	Post	Pre	Post
Burn 1	25	28	23	23	42	40
Unburned	85	103	87	102	118	129

DISCUSSION AND MANAGEMENT IMPLICATIONS

Based on the temperatures recorded by the thermocouples and thermal tiles, we are confident that all *A. johnstonii* within a plot were burned or exposed to realistically intense heat above the soil surface. Abiotic factors among the sites although variable, were moderate. The lower elevation Quinn and Kenworthy sites had higher fuel and soil moisture than the higher elevation McGregor site.

Based on the fire weather conditions recorded, the 1 kg of standardized fuels that was added to each plot aptly normalized the fire behavior, treatment and combustion among all plots on all sites. By adding fuel, we were able to test if *A. johnstonii* would survive fire under conditions that might occur when precipitation promoted more herbaceous fuels or when *A. johnstonii* grew with heavier fuels, such as under shrub canopies. Plots at McGregor recorded somewhat lower maximum fire temperatures above ground during the burns. Several factors that may have contributed to this are: it is higher in elevation, it was the first site burned in the early morning, soil composition had a higher rock content which may have also affected thermocouple placement.

The placement of the thermocouples and thermal tiles or the character of the soil substrate may have contributed to variable temperatures recorded. Even still, adequate heat was dispersed within the fire cage to assure that all plants received some high thermal challenge. Duration of heat was shorter and more intense above than below ground. Below soil temperature increases took longer, but did not exceed maximum thermal threshold ranges (40-52^{o}C or 104-127^{o}F) reported for temperate zone herbaceous species during growing seasons for plant injury (Larcher 1975). This increased the likelihood that the tuberous root of the *A. johnstonii* would survive a fire of this intensity. *A. johnstonii* that occur in the immediate proximity of very heavy fuels supplied by chaparral or yellow pine may experience higher or more prolonged temperatures than what we applied.

Plant number increased 4.5 months after the fire in control plots but remained relatively static in the burn plots. Two *A. johnstonii* were obviously lost during the burns at Quinn, but among all sites, there was a net gain of one plant between pre- and post-burn observations. However, this net increase in the burned population numbers is considerably less than the 15 percent increase observed in the unburned population during the same growth period. As expected, plant size and cover were less in burned plots. In all cases, the entire plant was measured, which included all leaves, stalks and flowers without differentiating dried stalks that remained from previous seasons. These dried stalks all burned in the test fires. Loss of these stalks in the burn plots somewhat exaggerates the difference in dimensions between burned and unburned *A. johnstonii*. Long-term observations will show if fire intensity or soil heating affect plant vigor or viability. Results from the September 2003 fire indicate that mature *A. johnstonii* can survive and grow after being exposed to fire. Future plot measurements will determine what effect fire has on seed production and germination, seedling establishment, and population dynamics. Comparisons between grazed and ungrazed plots will be evaluated after one year to determine if this additional level of disturbance affected the plant density, size or reproduction.

The known fire dynamics of the associated vegetation suggests that *A. johnstonii* also evolved with fire as an environmental component. The initial response of *A. johnstonii* to fire in this experiment is encouraging since it was resilient enough to produce flowers within 5 months of being exposed to a late summer fire. This plant may be fire tolerant and we are hopeful that it one day can be easily incorporated into future fire management programs. The results from the January burn, to be collected later this year, will indicate whether *A. johnstonii* can also survive fire during a less phenologically optimal season.

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