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EFFECTS OF PRESCRIBED FIRE ON BIOLOGICAL SOIL CRUSTS
AND THEIR SUBSEQUENT RECOVERY IN A GREAT BASIN JUNIPER WOODLAND

Final Report to the Joint Fire Science Program

Project #01-3-3-34

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ABSTRACT

A prescribed burn was conducted in a juniper woodland approximately 40 km south of Tooele, Utah on 05 October 2006. Conditions were sub-optimal, and the fire did not encroach into mid- or late-successional areas; only the early-successional area burned successfully. This study evaluated the effects of the prescribed burn on biological soil crusts that occupy the soil surface and are important for soil stability, soil nutrient cycling, and the germination and survival of vascular plants. Biological soil crusts are composed primarily of cyanobacteria, green algae, lichens and mosses.

Mosses were rare under juniper trees, so the effects of the fire were negligible; the burn significantly reduced the cover of mosses under sagebrush and in shrub interspaces. Lichens were uncommon under juniper and sagebrush. They were more common in shrub interspaces, but because the fire was spotty and of low intensity in the interspaces, they were minimally affected there.

The burn significantly reduced the biomass of green algae and cyanobacteria under juniper and sagebrush; it was unaffected in the shrub interspaces. Similar trends were seen in algal density. This conclusion was confirmed by measurement of the density of green algae and cyanobacteria which also showed a significant decline in juniper and sagebrush understory, but not in the interspaces.

Nitrogen fixation was significantly reduced under juniper trees but not under sagebrush or in the interspaces. Nitrogen fixation was approximately an order of magnitude greater in the shrub interspaces than beneath juniper and sagebrush. Because the interspaces were not greatly affected by the burn itself, there was no significant impact on nitrogen fixation there.

In general, it appears that, while the burn negatively affected some components of biological soil crusts in some parts of the early successional stage of the juniper woodland, the overall impact on the crusts was minimal. If the intent of prescribed burning is a reduction in juniper, burning of early successional juniper woodland is

appropriate because most affected trees were killed. Control of sagebrush can likewise be accomplished by low intensity, cool season fires without eliminating the crust component. Due to the spotty nature of the fire in the shrub interspaces, where most biological soil crusts occur, they were only minimally affected by the fire and may provide a good source of algal inoculants to re-colonize the soil in the juniper and sagebrush vegetation patch types which were more affected by the fire. The data suggest that intense fires should be avoided due to the potential for greater encroachment into the shrub interspaces which contain the majority of biological soil crust organisms. This information, plus the fact that late successional juniper woodlands are difficult to burn, suggests that burning of early successional juniper may be a preferred method for controlling juniper encroachment on western rangelands.

EFFECTS OF PRESCRIBED FIRE ON BIOLOGICAL SOIL CRUSTS AND THEIR SUBSEQUENT RECOVERY IN A GREAT BASIN JUNIPER WOODLAND

INTRODUCTION

Pinyon-juniper woodlands occupy more than 19 million ha in the western United States (Buckman and Wolters 1987). Biological soil crusts are a key component of many arid and semiarid ecosystems in the western United States (Rosentreter and Belnap 2001), including pinyon-juniper woodlands (Ladyman and Muldavin 1996). Comprised primarily of cyanobacteria, algae, lichens, and mosses living at or near the soil surface (Belnap et al. 2001a), these living crusts influence soil stability (Belnap 2001; Warren 2001a), hydrology (Warren 2001b), and cycling of macro- and micronutrients (Belnap et al. 2001b, Evans and Lange 2001). They also affect the dispersal and germination of vascular plant seeds, as well as the survival and growth of seedlings (Belnap et al. 2001b). The body of research related to the response of biological soil crusts to fire, the secondary impacts to ecosystem functions they perform, and the dynamics of post-fire recovery is small. Limited published data from western shrubland and grassland communities indicate that biological soil crusts are highly susceptible to wildfires and very slow to recover (Johansen 2001). Recovery of their ability to cycle nutrients and stabilize the soil surface can also be expected to be slow, although this assumption remains largely undocumented. Information regarding the effects of fire on biological soil crust communities in pinyon-juniper woodlands is absent. The objectives of the present study included: (1) determine the nature and extent of damage to biological soil crust communities by documenting changes in their cover, biomass, species composition and ecosystem function after a prescribed burn, and (2) document recovery dynamics over two subsequent years.

MATERIALS AND METHODS

Study site

The study area was shared with the Sagebrush Steppe Treatment Evaluation Project (SageSTEP), also funded by the Joint Fire Sciences Program (project number 05-S-08). It was located at approximately 1700 m elevation on the eastern foothills of the Onaqui Mountains, approximately 40 km south of Tooele, Utah (40° 13' 48"N, 112° 27' 55" W). Long-term average annual precipitation in Toole is 45 cm (Table 1; Western Regional Climate Center 2008). Vegetation at the study site ranged from early- to late-successional juniper woodland. The early-successional stage was dominated by Wyoming big sagebrush (*Artemisia tridentata* var. *wyomingensis*) with scattered Utah juniper (*Juniperus osteosperma*) of various ages (Figure 1). Bluebunch wheatgrass (*Pseudoroegneria spicata*) and Indian ricegrass (*Achnatherum hymenoides*) were common grasses; various forbs, including bur buttercup (*Ceratocephala testiculata*), were also present. Moving across the successional continuum to the late-successional juniper woodland, juniper dominated to the exclusion of most other species. The soil

was Borvant gravelly loam derived from limestone alluvium; slopes were generally < 15% (US Department of Agriculture 2008).

Table 1. Mean monthly and annual precipitation (cm) at nearby Tooele, Utah during the course of the study. Also included are long-term (1896-2007) precipitation measures (Western Regional Climate Center 2008). Precipitation totals at Vernon, Utah, approximately 13 km south of the study site, averaged about 40% less than at Tooele, but records for the years of the study contained unacceptably large data gaps. The mean values are included for purposes of comparison.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2006	7.1	2.8	8.3	7.5	1.8	2.2	4.1	1.0	5.3	5.8	1.6	3.4	50.8
2007	4.3	4.5	6.5	1.0	2.3	1.8	5.6	1.4	4.2	2.8	1.2	8.3	43.7
2008	4.3	6.4	3.4	1.9	8.9	6.5	0.2	3.5	1.0	1.9	1.0	-	38.0
1896–2007	3.4	3.9	5.4	5.4	5.0	2.6	2.1	2.2	2.7	4.0	4.1	3.5	45.4
1953-2007 Vernon, UT	1.8	2.0	2.6	2.3	3.0	2.0	2.1	2.2	2.1	2.7	2.2	1.8	26.7

A prescribed burn was scheduled for the study area during the summer of 2006. However, the summer was characterized by multiple wildfires in the western United States and fire-fighting crews required to manage the prescribed burn were fully occupied until later than expected. The prescribed burn occurred on 05 October 2006. Due to the lateness of the season, characterized by cool temperatures, elevated humidity, and low winds, in addition to above-normal precipitation during September and October 2006, the burn was only minimally successful. Less than 30% of the targeted area burned, and even those areas were spotty. The fire did not carry into the mid- and late-successional juniper woodland. Hence, only the early successional stage of juniper encroachment could be included in the postburn evaluation.

Experimental design

Prior to the burn, we established 10 sets of 3 adjacent plots in each of three vegetation patch types present in the early successional juniper woodland. These included juniper understory, sagebrush understory, and the interspaces between the scattered shrubs and trees. Plots measured 0.5 x 0.5 m. In order to measure the intensity of the fire, we placed aluminum tags in the center of each plot. The tags measured 2 x 8 cm and were painted with successive lines of temperature sensitive paints. The lines of paint were subject to melting at 79, 121, 177, 232, 288, 343, 399, 454 and 510°C. The intensity of the fire at each plot was estimated by calculating the midpoint between the temperature rating of the last melted paint line and the subsequent unmelted line. Where none of the lines were melted, the temperature was estimated as 56°C (the midpoint between the average maximum ambient air temperature of 32°C and the lowest rated paint or 79°C). Where all of the lines were melted, the temperature was estimated as 540°C.

Figure 1. Typical views of the juniper (above) and sagebrush (below) vegetation patch types present at the study site south of Tooele, Utah. Interspaces between the juniper and sagebrush plants are visible in both photographs.

Following the burn, a duplicate set of plots was established in an unburned portion of the study site for use in comparing burned versus unburned conditions.

All plots were permanently delineated by driving lengths of 1-cm diameter metal rod into the ground at each corner, with approximately 5 cm extending above the soil surface. Aluminum tags with the plot identification were attached to one of the rods at each plot. The location of each plot was also recorded with a global positioning system in order to assist in relocating them on subsequent visits.

One plot in each set of 3 was used for ocular estimation of cover of biological soil crust organisms and vascular plants ('cover' plots). One plot was used for biotic analyses including algal biomass, density and species identification ('biotic' plots). The remaining plot was used for destructive sampling to determine nitrogen fixation rates ('soil' plots).

Data collection

Data were collected in burned and unburned plots soon after the burn (mid-October 2006) and again in September 2007 and June 2008. For ocular estimates and sample collection, a 0.5 m x 0.5 m plot frame was constructed of ¾ inch diameter PVC pipe. The numbers 1 - 9 were inscribed at 5-cm intervals on one side of the plot and the letters A - I were inscribed in a similar fashion on a perpendicular side. This design created a grid of 100 squares and 81 grid intersections. At each sampling date, the plot frame was lowered over each 'cover' plot, using the corner markers as guides for correct placement. We made ocular estimates of the percent cover of lichens, mosses, vascular plants, rocks, and organic litter. Lichens were recorded by species and as a total.

The plot frame was also placed over each of the 'biotic' plots. Small core samples (1 cm in diameter and 1 cm deep) were taken at 10 predetermined random grid intersections for each sample date. The 10 sub-samples per plot were combined into one composite sample for use in determining algal biomass, algal enumeration, and species identification. Randomization was done without replacement such that no point was re-sampled over the course of the study.

Finally, the plot frame was placed over each of the 'soil' plots. We collected 2 larger cores (10 cm diameter by 6 cm deep) per plot from randomly determined grid intersections on each sample date. These cores were collected intact and transported to the soil laboratory at Brigham Young University for determination of nitrogen fixation rates using acetylene reduction techniques. As in the case of the 'biotic' plots, the sample locations were determined randomly and without replacement for each plot.

Biotic analyses

Algal biomass. Chlorophyll *a* is often used as an index for measuring productivity or biomass of cyanobacteria in the soil. We used the methods of Bell and Sommerfield (1987) as modified by Kasper (1994). Soil samples were passed through a 2 mm sieve to remove rocks and large organic particles. We took three 1.5 g subsamples from the composite sample from each 'biotic' plot and placed them in centrifuge tubes. Five ml of dimethyl sulfoxide (DMSO) were added to each tube and the tubes were shaken thoroughly. The samples were heated to 65°C in dim light conditions to prevent degradation of the chlorophyll. After 30 minutes the samples were again shaken vigorously and returned to the oven for an additional 30 minutes. The samples were then removed from the oven and allowed to cool. After cooling, the samples were centrifuged and the supernatant was decanted into a test tube. The supernatant was then filtered through a glass fiber filter to remove all residual clays and particles that could interfere with quantification. We deviated from the method of Kasper (1994) by determining chlorophyll fluorometrically. The fluorometer was re-standardized for each sample date with known chlorophyll standards from Sigma Scientific Supply to ensure comparable results between sampling periods.

Algal identification. In order to isolate and identify algal taxa before and after the burn, dilution plate methods were employed (Johansen et al. 1993), utilizing Z-8 medium (Carmichael 1986). We determined that 10^3 dilution plates represented an ideal dilution rate for our sites, and all samples were plated in triplicate. The culture collection was maintained at 200 µE illuminance on a 12:12 hour light:dark cycle. Over 200 strains were isolated during the course of the study, but far fewer species were recovered, as many species had numerous representative strains. Taxa were identified based on morphology and life history as observed under a light microscope. Two photomicroscopes were utilized (Olympus B-Max, Zeiss Axioskop), both equipped with high resolution Nomarski DIC and epifluorescence optics.

Algal density. Beginning on the second sample date, in order to enhance our interpretation of the biomass analyses, we began determining the density of cyanobacteria and green algae in the soil samples. Fluorescence microscopy was used to measure density. The method was modified from that of Johansen and Rushforth (1985), is described briefly in Buttars et al. (1998), and in detail in Kasper (1994). This method is a direct count method and is appropriate for enumerating soil algae without the bias introduced by culturing. It is only effective in soils with high densities of cyanobacteria and algae, and was especially helpful in the unburned interspace and sagebrush sites. From each biotic sample we removed a 0.5 g subsample. The subsample was placed in a tissue grinder (15 ml) with a plunger rod consisting of a steel and plastic head. A total of 5 ml of water was added, the sample was ground, and the liquid (thoroughly agitated) was placed into a Tchan counting chamber (Tchan 1952, Johansen and Rushforth 1985). We counted a total of 10-20 transects (1.0 cm in length) per slide (higher numbers of transects were counted when numbers of organisms were low). Algae were examined at 400X magnification. Samples were examined under an epifluorescence microscope using wide-band blue and wide band green excitation

filters. Cyanobacteria and green algae both fluoresce bright red with the wideband green, and this was the filter most commonly used. Other objects can fluoresce with this excitation filter, and the more restrictive filter was used to check dubious fluorescing objects to determine whether or not they were indeed photosynthetic micro-organisms. The Nomarski DIC prisms were removed during epifluorescence to enhance the image.

Nitrogen fixation

Nitrogen fixation rates were estimated using acetylene reduction techniques (Terry and Jolley 1994). Samples were collected from the field using a PVC coring device to remove undisturbed soil profiles 10 cm in diameter and 6 cm deep from the 'soil' plots. Core containers were sealed with plexiglass covers with pre-drilled holes designed to accommodate rubber stoppers equipped with glass tubes containing rubber septa. The cores were moistened with water and a volume of acetylene was added to provide a 10% acetylene concentration. Samples were incubated for 24 hours in a growth chamber. A 0.25 ml air sample was then taken from the incubation container and analyzed for ethylene using an HP 5890 series II gas chromatograph equipped with a flame ionization detector. The following equation was used to convert ethylene concentration to nitrogen fixation:

$$\text{mmolN}_2 \text{ m}^{-2} \text{ hr}^{-1} =$$
$$(((\text{(ethylene peak)(nl headspace)}(1/27.8 \text{ nl}))/((24 \text{ hrs})(\text{surface area})))/3)(10{,}000)$$

Statistical analyses

Data were analyzed by multifactor analyses of variance. For the purpose of statistical analyses the burned versus unburned plots represented treatments, as did the vegetation type and sample date. Dependent variables included cover variables, density of cyanobacteria and green coccoid algae, chlorophyll *a*, and nitrogen fixation.

RESULTS AND DISCUSSION

Burn characteristics

As noted in the Materials and Methods section, the prescribed fire was spotty and limited to the early-successional juniper woodland. Fine fuel loads typically decline as juniper stands mature (Barney and Frischknecht 1974); consequently, late successional juniper stands are often difficult to burn (Martin 1978, Bunting 1987). Hence, it is not surprising that the burn did not encroach into the mid- and late-successional juniper communities. In the present study, the fuel load in the shrub interspaces of even the early-successional juniper woodland was limited; the fire scarcely passed through this patch type and the surface temperature was consistently below the minimum recorded. The mean temperature of the fire under sagebrush was

377°C. The mean temperature under the juniper was significantly higher at 441°C. The temperature of the fire was not significantly correlated with any of the measured biotic variables.


Organic cover

Juniper was present only in juniper plots; it was not present in sagebrush or interspace plots. Within juniper plots, mean cover of live juniper prior to the burn was 98%. Although dead juniper remained standing, cover of live juniper was eliminated by burning, indicating complete kill of all trees sampled (Figure 2). No recovery was detected during the first 20 months following the fire. Utah juniper is known to be susceptible to fire (Barney and Frischknecht 1974). Mortality is highest among mature trees when 60% or more of the canopy is scorched (Springfield 1976). Except for individual trees that escape burning, recovery is by seed and it typically requires 10 years or more for juniper to reappear (Barney and Frischkneckt 1974).
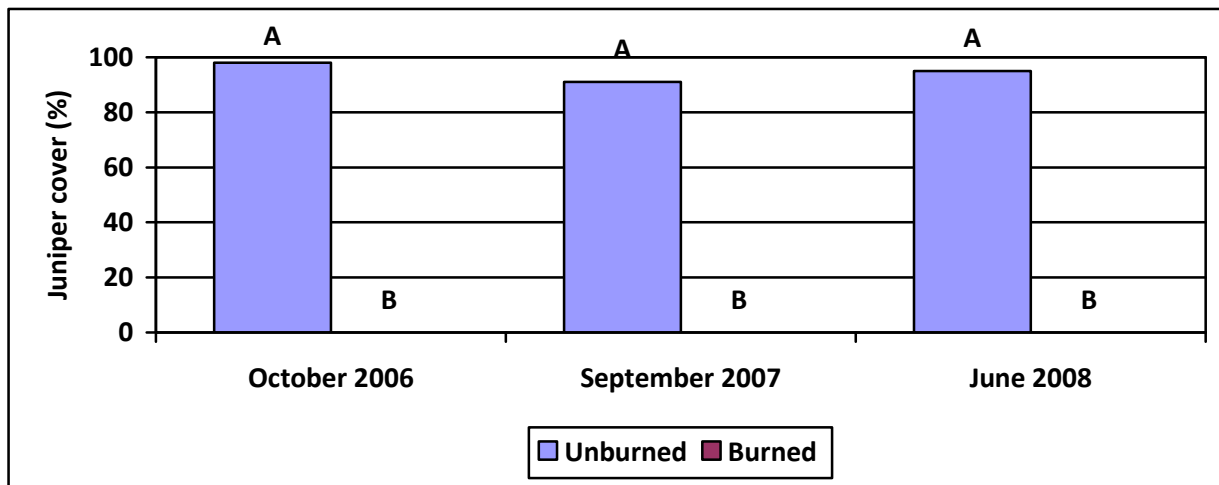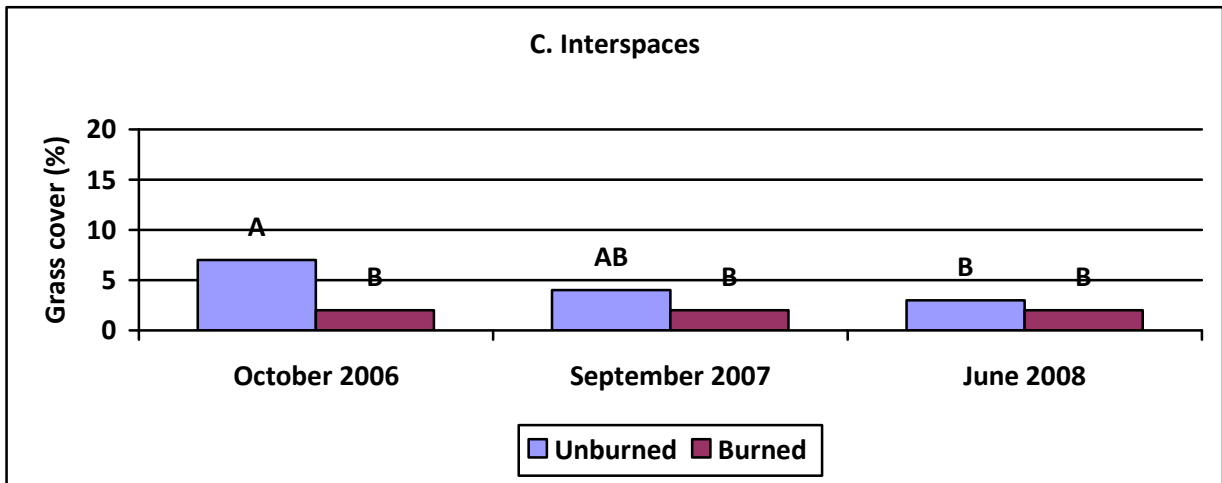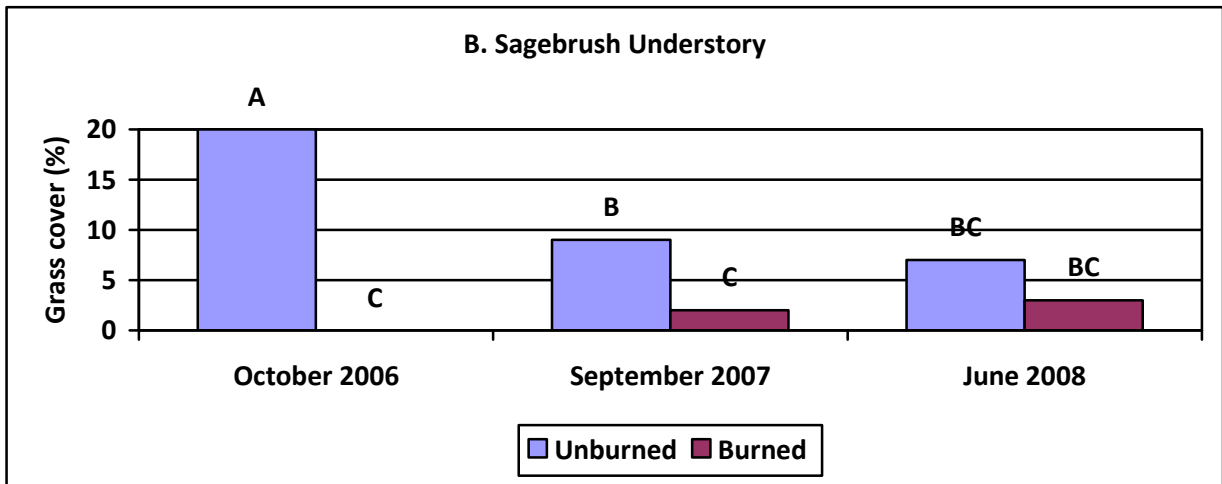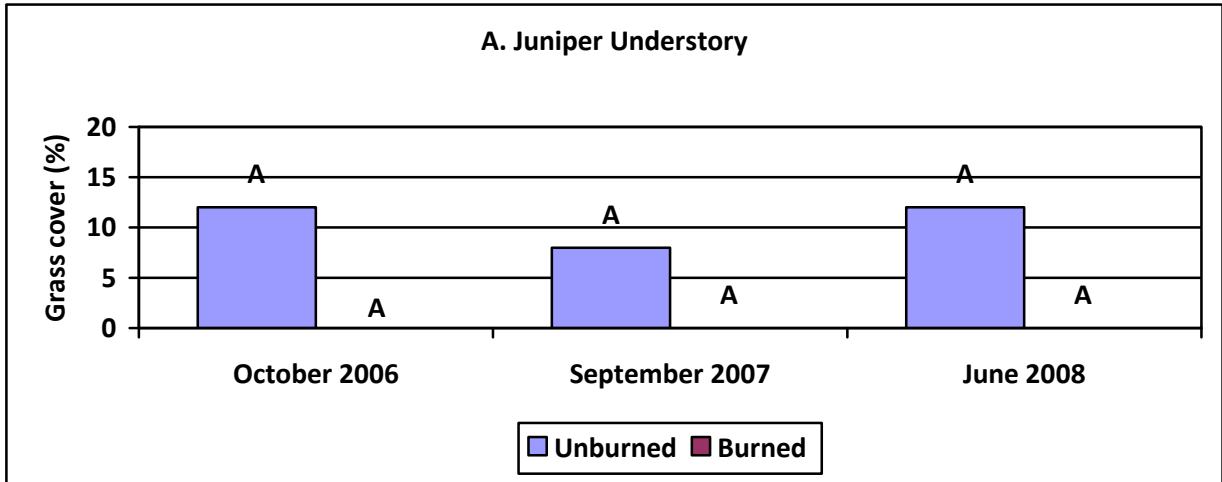

Figure 2. Percent cover of juniper in unburned and burned juniper understory plots following a prescribed burn south of Toole, Utah on 05 October 2006. Bars with the same letter are not significantly different at α=0.05.

Sagebrush was present only in sagebrush plots; it was not present in the juniper or interspace plots. The mean cover of live sagebrush in sagebrush plots prior to the prescribed burn was 97%. Where the fire burned through the sagebrush plots, it typically consumed all organic matter above the soil surface. Live sagebrush cover on those plots was eliminated by the fire, suggesting complete kill of sagebrush that were burned (Figure 3). No germination of seeds was noted in the 20 months following the burn. Wyoming big sagebrush typically ignites readily and produces a hot fire (Neuenschwander 1980). Most individuals are killed by fire (Wambolt and Payne 1980). Reproduction is by seed, and seedlings may appear within 3 years (Barney and Frischkneckt 1974).

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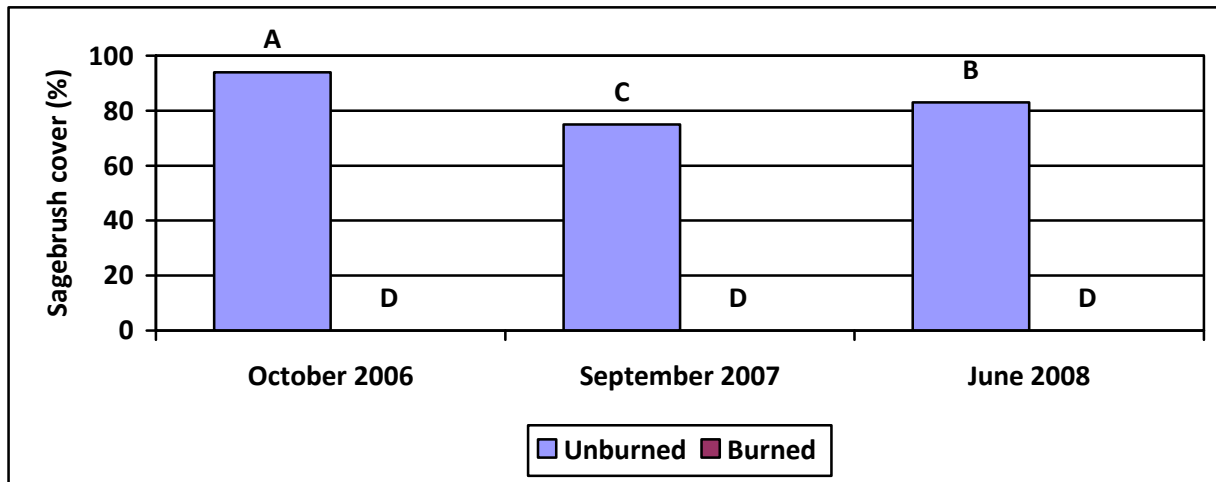
Figure 3. Percent cover of sagebrush in unburned and burned sagebrush understory plots following a prescribed burn south of Tooele, Utah on 05 October 2006. Bars with the same letter are not significantly different at α=0.05.

Grass species occurred in plots of all vegetation patch types prior to the burn. Soon after the fire, the cover of grass in the sagebrush understory and interspaces was significantly reduced (Figure 4). The fire essentially eliminated grass cover in the juniper understory, but because of high variability in cover in the preburn condition, the elimination of the grass cover in the postburn condition was not statistically significant. The trend did not change over the subsequent 20 months. Grass cover in the sagebrush understory plots was significantly reduced by the fire and remained lower in burned plots compared to unburned plots throughout the study, although the difference was no longer significant by the last sample date. The cover of grass in interspace plots was significantly reduced by burning at the first sample date, but had recovered to a level comparable to the unburned condition after one year. There was a significant decline in grass cover in both the unburned sagebrush understory and interspace plots over the course of the study, becoming statistically significant in the sagebrush understory within one year and within the interspaces after 20 months. The decline in grass cover on the unburned sagebrush plots in 2007 and 2008 is unusual, particularly given the overall higher than normal precipitation in those years (Table 1). However, the decline seems to mirror a decline in sagebrush cover on the same plots (Figure 3). The decline in grass cover in the unburned sagebrush and interspace plots may be due to less favorable microclimatic conditions created by the general removal of vegetation in adjacent burned areas.
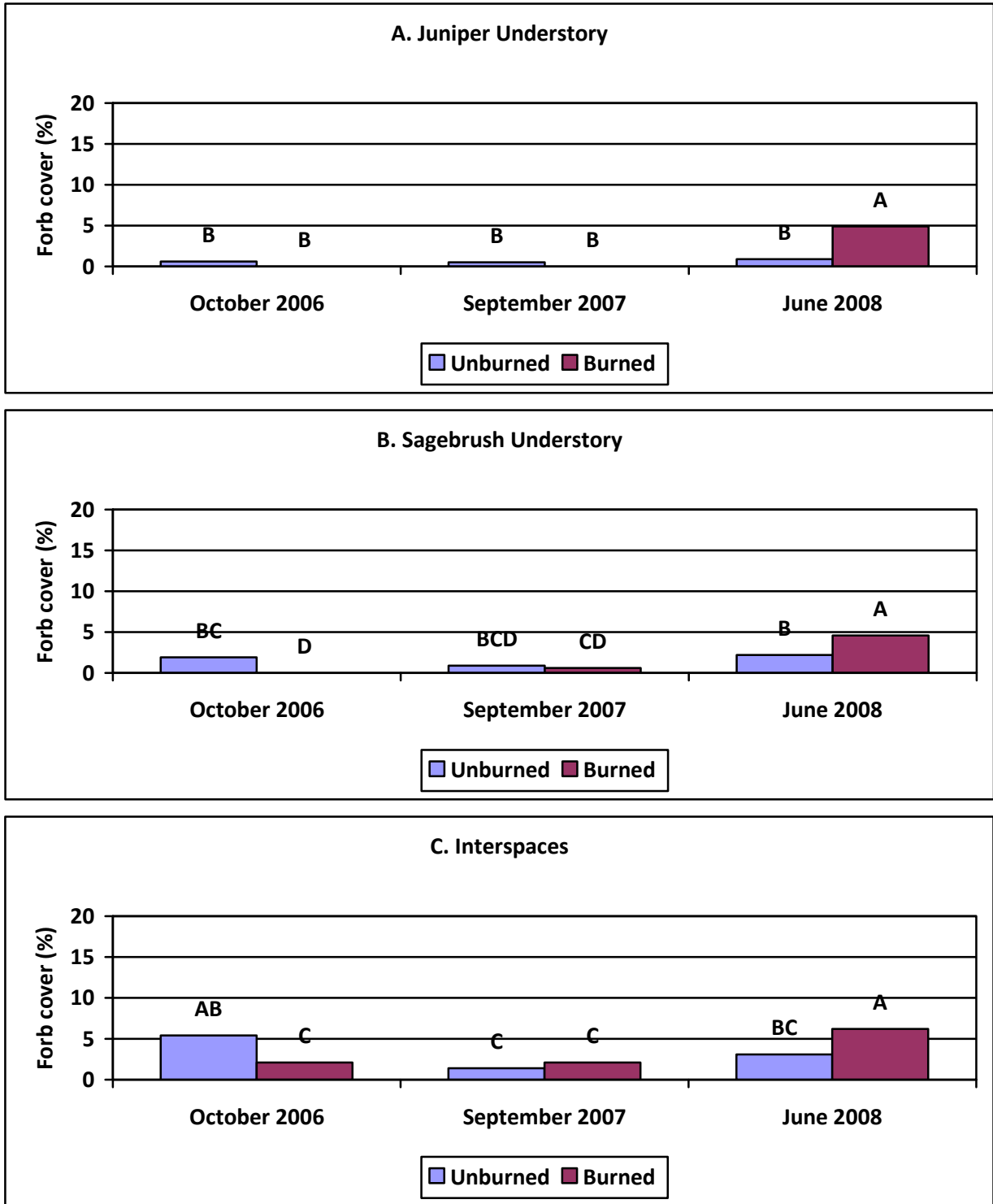
Figure 4. Percent cover of grass in unburned and burned juniper understory plots (A), sagebrush understory plots (B), and interspace plots (C) following a prescribed burn south of Tooele, Utah on 05 October 2006. Bars labeled with the same letter within a vegetation patch type are not significantly different at α=0.05.

Forbs were scarce in all three vegetation patch types. Forb cover was reduced in all burned plots at the first postburn sample date, although the difference was significant only in the sagebrush understory and interspaces (Figure 5). Forb cover declined significantly in the unburned interspace plots over the first year. There were no statistically significant differences in forb cover between unburned and burned conditions for any of the vegetation patch types one year following the burn. On the final sample date, 20 months following the burn, there was an increase in forb cover in the burned plots of all three vegetation patch types, a likely response to the higher than normal precipitation in May and June of 2008 accompanied by a postburn flush of nutrients and exposure of germination microsites with the removal of vegetative cover. Enhanced germination, survival, and growth of forbs in burned micro-sites have been noted in other sagebrush communities (Wirth and Pyke 2003, Wrobleski and Kauffman 2003). There were no notable changes in forb cover within unburned plots under juniper and sagebrush. Within the interspaces, forb cover was significantly lower one year following the burn, but returned to preburn levels after 20 months.

Organic litter under unburned juniper was uniformly high and did not vary over the course of the study (Figure 6). The fire consumed all organic litter under burned juniper but this was replaced within a year by dead leaves and branchlets from the burned canopy. This new litter had significantly deteriorated by the 20th month after the fire. Organic litter under sagebrush declined over the course of the study in both the unburned and burned plots, becoming significant at the last sample date. Litter cover in the shrub interspaces also declined significantly by the last sample date in the unburned plots.

Bryophytes were rare in the juniper understory in both the burned and unburned plots (Figure 7). Bryophyte cover was more prevalent under sagebrush and in the interspaces, and tended to decline over time in both the unburned and burned plots, although the differences were significant only in the unburned plots. A significant decline in bryophyte cover following fire has been noted in other published studies related to rangelands of the western United States (Antos et al. 1983, Johansen et al. 1984, 1998). Bowker et al. (2004) detected a large but statistically insignificant decline in bryophyte cover following a fire in the Palouse region of the Pacific Northwest. Schulten (1985) also reported a reduction in moss cover following burning of sand prairie in southeastern Iowa, but the difference was not statistically significant.
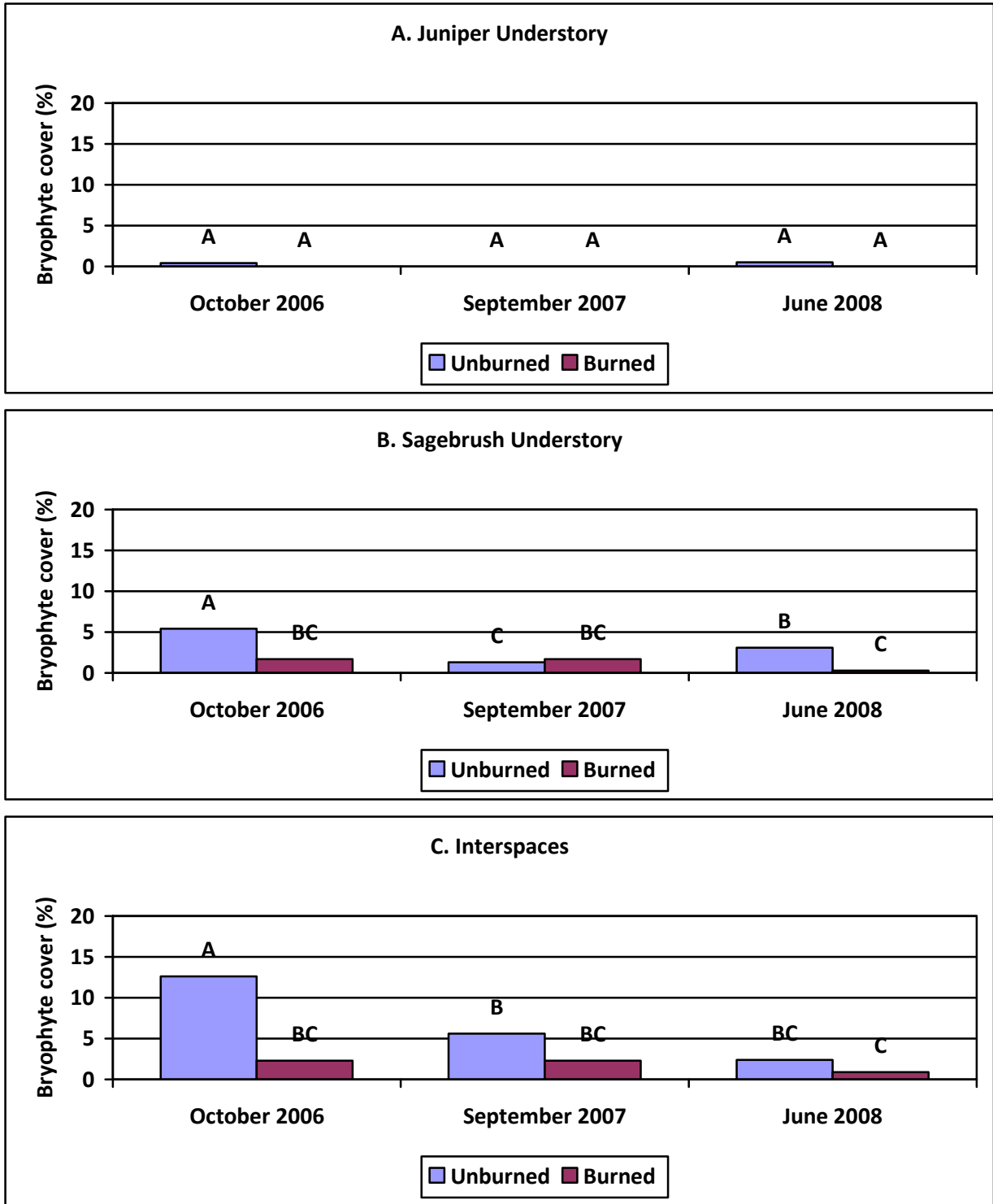
Figure 5. Percent cover of forbs in unburned and burned juniper understory plots (A), sagebrush understory plots (B), and interspace plots (C) following a prescribed burn south of Tooele, Utah on 05 October 2006. Bars labeled with the same letter within a vegetation patch type are not significantly different at α=0.05.
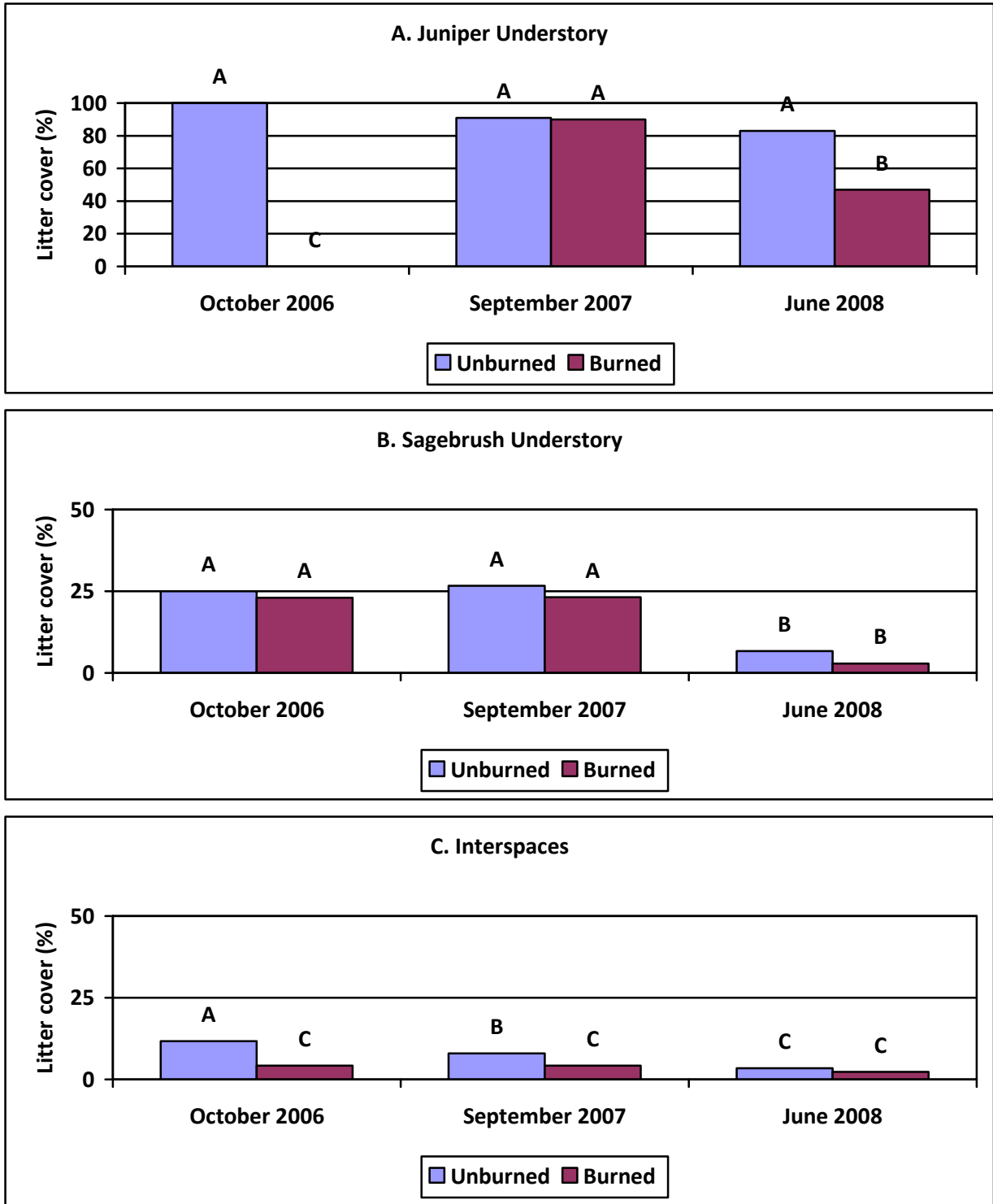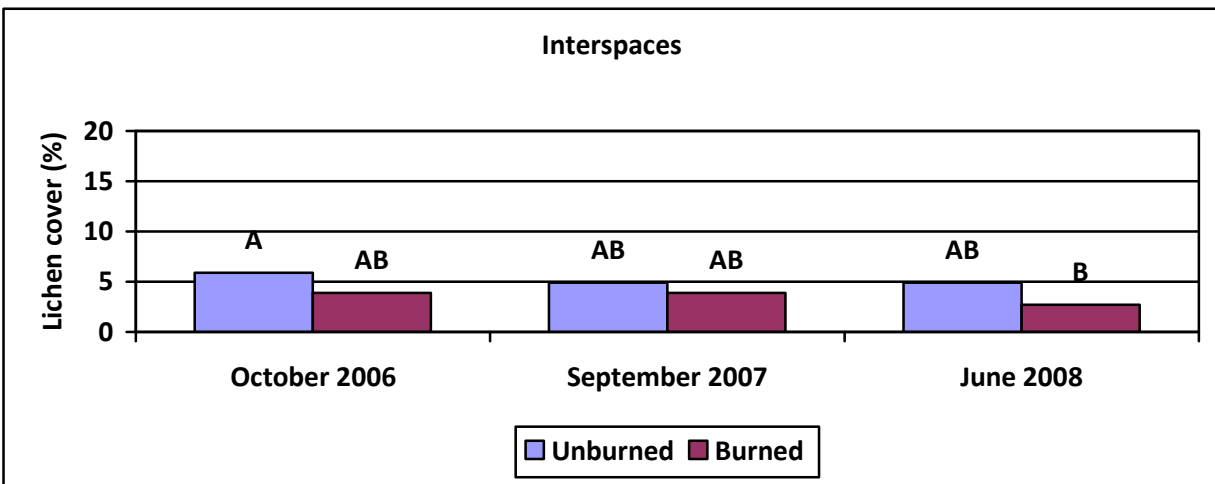
Figure 6. Percent cover of litter in unburned and burned juniper understory plots (A), sagebrush understory plots (B), and interspace plots (C) following a prescribed burn south of Tooele, Utah on 05 October 2006. Bars with the same letter within a vegetation patch type are not significantly different at α=0.05.

Figure 7. Percent cover of bryophytes in unburned and burned juniper understory plots (A), sagebrush understory plots (B), and interspace plots (C) following a prescribed burn south of Tooele, Utah on 05 October 2006. Bars with the same letter within a vegetation patch type are not significantly different at α=0.05.

Lichens were essentially absent beneath juniper and sagebrush. Hence, the fire had little impact on their abundance. Although there were more lichens in the interspaces, the effect of the burn there was minimal (Figure 8). Some other studies have suggested that fire significantly diminishes lichen cover in rangeland communities (Antos et al. 1983, Johansen et al. 1984, Hilty et al. 2004, Ponzetti et al. 2007, Schulten 1985). Of the studies suggesting a decline in lichens, only Antos et al. (1983) were able to provide sufficient information on the timing and aftermath of the burn to suggest that it was intense. Nevertheless, it stands to reason that intense fires are likely detrimental to lichen survival. Bowker et al. (2004) found that a low intensity fire in the Palouse prairie had minimal impact on lichen cover. This corroborates the results of the present study where the low intensity, spotty fire produced no significant difference in lichen cover between burned and unburned areas. A number of lichen species were present. These included *Aspilicia fruticosa*, *A. hispida*, *Buellia elegans*, *Caloplaca tominii*, *Collema tenax*, *Fulgensia bracteata*, *Psora cerebriformis*, *P. decipiens*, *P. tuckermanii*, *Placidium squamulosum* and *Toninia sedifolia*. The species that occurred most frequently were *A.hispida*, *C. tominii* and *C. tenax.*
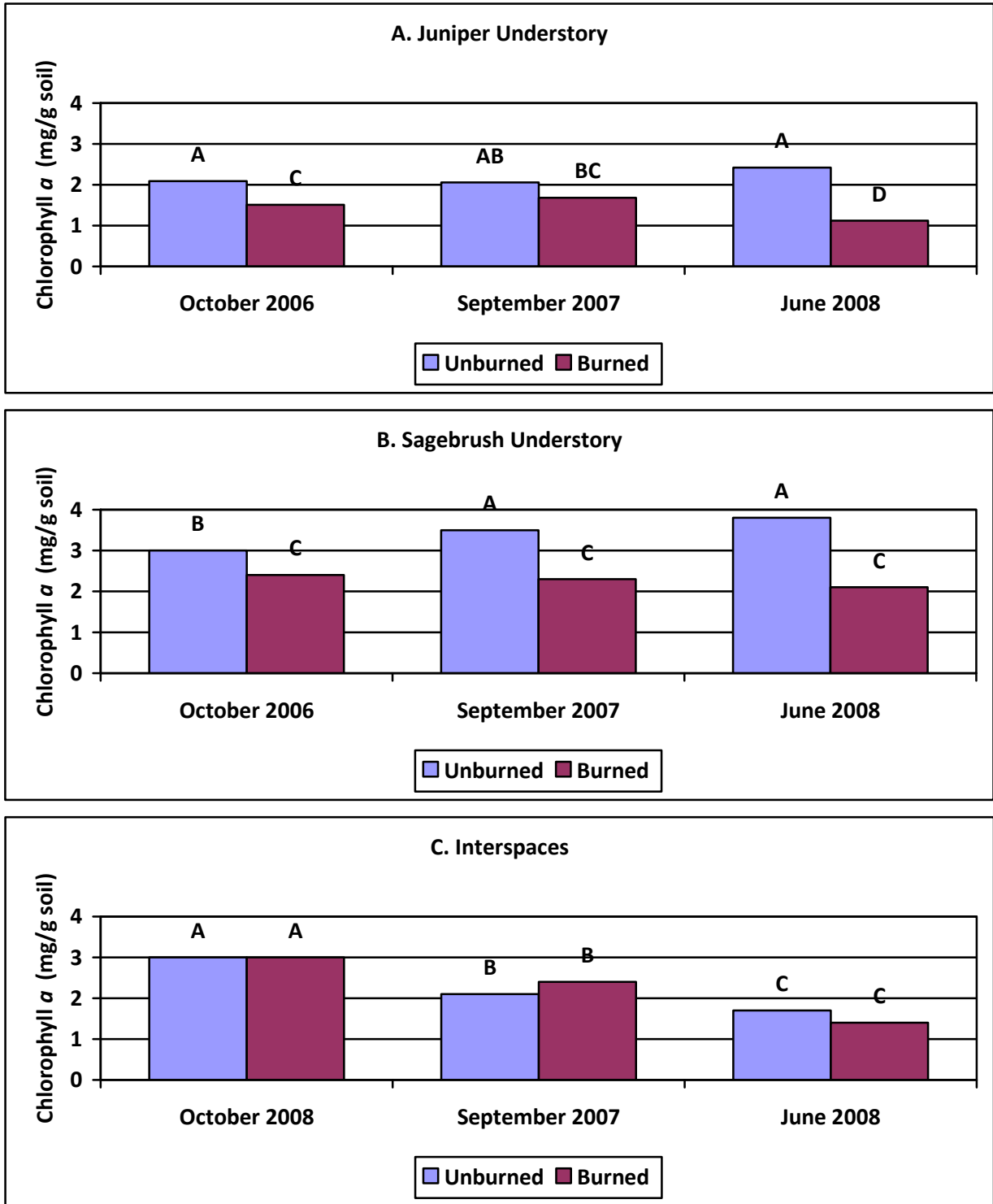

Figure 8. Percent cover of lichens in unburned and burned interspace plots following a prescribed burn south of Tooele, Utah on 05 October 2006. Bars labeled with the same letter are not significantly different at α=0.05. Lichens were essentially absent under juniper and sagebrush.

Algal biomass

As a measure of algal biomass, the chlorophyll *a* content in the soil of burned and unburned plots within the vegetation patch types is presented in Figure 9. Chlorophyll *a* content of the soil beneath juniper and sagebrush understory declined as a result of the prescribed burn and remained at a reduced level for the remainder of the study. This suggests significant mortality among chlorophyll-bearing organisms, primarily green algae and cyanobacteria, at the time of the fire. Similar declines following fire have been detected in a sagebrush community in Idaho (Rychert 2002), a greasewood community in Utah (Kasper 1994), and the Palouse prairie of Oregon (Bowker et al. 2004). Ford and Johnson (2006) reported a decline in chlorophyll a following a dormant season burn in the shortgrass steppe of New Mexico, but not following a growing season burn. Chlorophyll *a* content in the shrub interspaces was not reduced by the prescribed burn, confirming the minimal impact of the burn on the interspace patch type as evidenced by visual observation and measurement of other biotic parameters. However, of particular note, the chlorophyll *a* content of unburned and burned interspaces declined in the months following the fire and continued to decline through the end of the study. This may be indicative of the somewhat drier conditions in 2007 and greater insolation and exposure to desiccating winds following the removal of the adjacent shrubs. Chlorophyll *a* content of the burned juniper plots also declined over the course of the study. Chlorophyll *a* content in burned sagebrush plots likewise declined over time, but the decline was not statistically significant.

Algal density

In order to more fully understand differences in chlorophyll a content of the soils in the study plots, the density of green coccoid algae and cyanobacteria were determined beginning with the second sample date. The results are shown in Figures 10 and 11, respectively. Both groups were present in all vegetation patch types one year after the prescribed burn and either maintained comparable numbers or declined in density by 20 months following the burn. Both groups were most abundant in the shrub interspaces and least abundant under juniper canopy. The relative density of these organisms in burned versus unburned plots of the different vegetation patch types corresponds roughly with the relative biomass of soil algae in burned and unburned conditions within the same vegetation patch types (Figure 9). This suggests that, while the biovolume of soil algae may vary, density is a reasonable approximation of biomass. That being the case, a significant reduction in the density of green coccoid algae and cyanobacteria in mixed shrubland in Utah (Johansen et al. 1982) and a sagebrush community in Washington (Johansen et al. 1993) correspond to a reduction of biomass as approximated by chlorophyll *a* in the study herein.
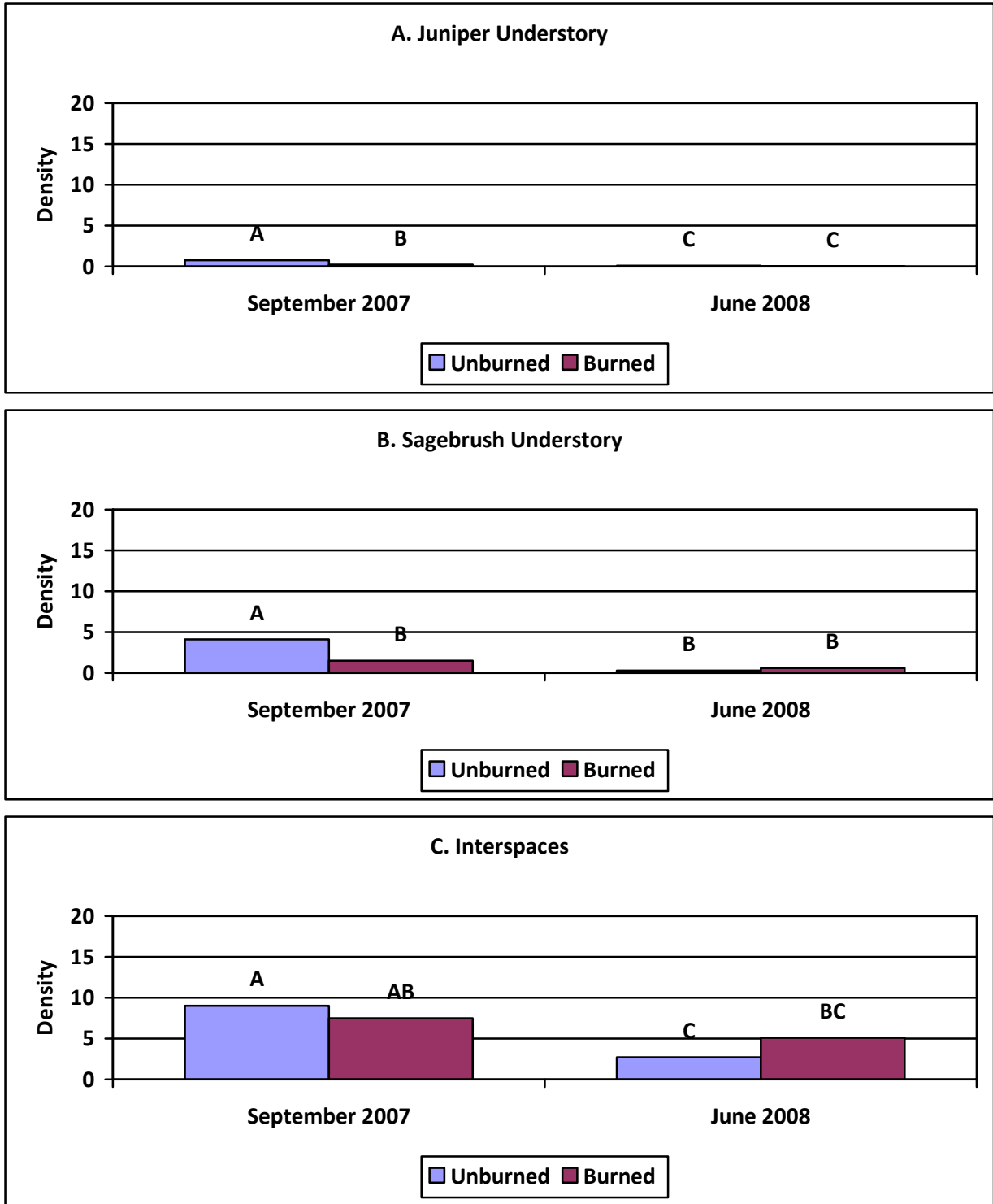
Figure 9. Chlorophyll *a* content of the soil of unburned and burned juniper understory plots (A), sagebrush understory plots (B), and interspace plots (C) following a prescribed burn south of Tooele, Utah on 05 October 2006. Bars with the same letter within a vegetation patch type are not significantly different at α=0.05.
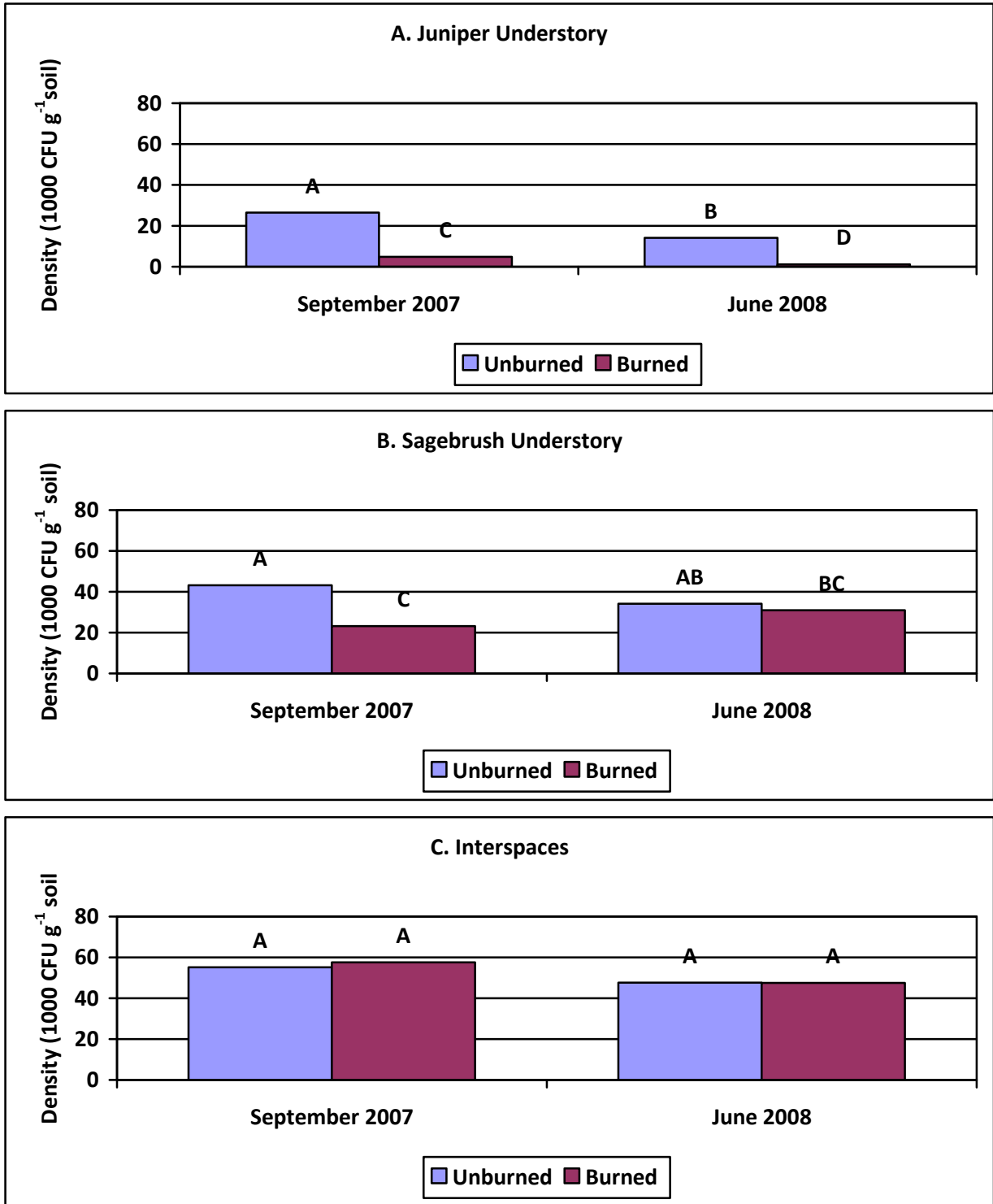
Figure 10. Density of green coccoid algae in the soil of unburned and burned juniper understory plots (A), sagebrush understory plots (B), and interspace plots (C) following a prescribed burn south of Tooele, Utah on 05 October 2006. Bars with the same letter within a vegetation patch type are not significantly different at α=0.05.

Figure 11. Density of cyanobacteria in the soil of unburned and burned juniper understory plots (A), sagebrush understory plots (B), and interspace plots (C) following a prescribed burn south of Tooele, Utah on 05 October 2006. Bars with the same letter within a vegetation patch type are not significantly different at α=0.05.

Algal diversity

An effort was made to isolate all algal species present in burned and unburned plots soon after the burn to ascertain the effect of the fire on algal species diversity. A total of 52 distinct algal morphotypes were observed, including 21 cyanobacteria, 26 chlorophytes, and 5 tribophytes (Table 2). This is relatively high diversity in comparison to algal floras reported previously from this region (Johansen et al. 1984, Johansen and St. Clair 1986, Johansen and Rushforth 1985), likely due to the greater resolution in the eukaryotic algae possible with more modern taxonomic treatments. The shrub interspace areas had highest algal diversity, with little difference in preburn and postburn species richness (29 and 27 taxa, respectively). The preburn sagebrush understory area had comparable diversity, with 24 taxa. However, the fire appeared to damage the algal community in sagebrush understory, as diversity dropped to 11 taxa after the fire. Juniper understory supported notably fewer algal species, with only 11 taxa before the fire, and 7 taxa after the fire. It is also notable that under juniper there were relatively few algae present at all, as most taxa collected in these communities were represented by a single isolate.

Some interesting shifts occurred in the cyanobacterial communities following the burn, even in the less affected shrub interspaces. In dilution plates prior to the burn, *Microcoleus vaginatus* was a clear dominant, and over 20 isolates were made from these plates. This easily identified alga decreased in abundance notably after the fire. We suspect the increase in Oscillatoriineae in interspace plots after the fire may be an artifact due to the absence of *M. vaginatus* from many of the plates. This taxon overgrows the plates when present, and likely prevents the emergence of the slower growing taxa, *Aphanothece* sp., *Borzia periklei,* and *Microcoleus steenstrupii.* We also noted a shift in the distribution of *Nostoc* species in these communities (Table 2).

The heterocystous taxa, which have the potential to fix atmospheric nitrogen, were clearly more abundant in the shrub interspaces. Their presence was depressed in the sagebrush understory, and they were absent altogether from the juniper understory.

The eukaryotic algae (chlorophytes and tribophytes) demonstrated more even species richness across vegetation patch types than was seen in the cyanobacterial community. Depression in richness was evident in the juniper understory, and occurred in response to fire. Species diversity for eukaryotic species was actually highest in the sagebrush understory, although after the fire diversity had dropped by over half. The dominant genera were *Chlorella* and *Xanthonema.*

Table 2. Algal species present in vascular plant communities before and after the fire. PI=preburn interspace between shrubs, PS=preburn sagebush understory, PJ=preburn juniper understory, BI=postburn interspace between shrubs, BS=postburn sagebrush understory, BJ=Postburn juniper understory. Abundance codes are based on the number of isolates obtained for each species, and are: P=present (only 1 isolate), I=infrequent (2-4 isolates), C=common (5-10 isolates), A=Abundant (11-25 isolates).

	PI	PS	PJ	BI	BS	BJ
CYANOBACTERIA						
Synechococcineae						
Leptolyngbya crispata	I	I		I		
Leptolyngbya foveolarum	C	I		C	P	
Leptolyngbya tenuis	I			P		
Leptolyngbya sp.	C	C		C		
Protolyngbya sp.				I		
Trichocoleus sp.	I					
Oscillatoriineae						
Aphanothece sp.				P		
Borzia periklei				I		
Cyanosarcina sp.				I		
Microcoleus steenstrupii				P		
Microcoleus vaginatus	A	I	P	I		
Nostocineae						
Hassallia bouteillei	P					
Hassallia sp.	P					
Nostoc desertorum				I	P	
Nostoc indistinguendum	I	I		C		
Nostoc sphaericum	P					
Nostoc sp.	A	I		C		
Tolypothrix distorta	P					
Tolypothrix tenuis f terrestris				P		
Tolypothrix sp.	I			C		
Trichormus sp.	C				P	
CHLOROPHYTA (green algae)						
Bracteacoccus sp.	P	I	I	P	I	P
Chlamydomonas sp.						P
Chlorella minutissima	I	C	I	I	I	C
Chlorella sp.	P		P	I		
Chlorococcum sp.						
Chlorosarcina sp.				I		
Coccomyxa sp.	P	P	P		P	
Cystomonas sp.		P				

	PI	PS	PJ	BI	BS	BJ
CHLOROPHYTA (continued)						
Dictyochloris sp.	P					
Diplosphaera chodatii		P	P			
Diplosphaera sp.		I				
Elliptochloris sp.			P			
Fasciculochloris sp.		P				
Follicularia sp.				P		
Macrochloris sp.		I		P	P	
Myremecia sp.	I	P	I		I	P
Neochloris sp.						
Pseudotetracystis sp.	I	I	P	P		P
Radiosphaera sp.		P		I		
Scenedesmus sp.	P	I	P	P		
Spongiochloris sp.	P					
Stichococcus bacillaris		P				
Tetracystis sp.	P	P				
Trebouxia showmanii	P					
Trebouxia sp.	P	I				
Trochisciopsis tetraspora		P			P	I
TRIBOPHYTA (yellow-green algae)						
Botrydiopsis sp.	P					
Heterococcus capitatus				P		
Heterococcus sp.		P		C	P	P
Xanthonema montanum	P					
Xanthonema sp.	C	C	I	C	I	
Cyanobacterial species richness	14	6	1	15	3	0
Eukaryotic species richness	15	18	10	12	8	7
Total algal species richness	29	24	11	27	11	7

Nitrogen fixation

Nitrogen fixation in the soil beneath juniper declined significantly as a result of the burn (Figure 12). Thereafter, nitrogen fixation declined significantly in both the unburned and burned plots. Nitrogen fixation in the soil beneath sagebrush was generally low and exhibited no distinguishable trend over the course of the study except for a statistically significant spike in the unburned plots on the last sample date. Shrub interspaces supported much higher nitrogen fixation than plots located beneath juniper or sagebrush. There was no distinguishable immediate response to burning. Nitrogen fixation was significantly lower one year following the burn in both the burned and unburned plots and remained at a diminished level until the last sample date, following a similar trend observed in plots located beneath junipers. Nitrogen fixation levels in the interspaces were approximately five times greater than beneath juniper. However, differences in the biomass and density of green algae and cyanobacteria between the vegetation patch types were inadequate to explain the differences in nitrogen fixation.

Although few other studies have examined the effects of fire on nitrogen fixation by biological soil crusts in western ecosystems, they tend to confirm the absence or diminutive nature of short term effects. Burns (1983) found no difference in nitrogen fixation between unburned and recently burned sagebrush grasslands about 50 km east of our study site. Ford and Johnson (2006) detected a significant reduction in nitrogen fixation soon after a dormant season burn in a desert grassland in New Mexico, but not after a growing season burn. Within a year, the differences had disappeared. Four years following a summer burn in a desert shrubland in Utah, Johansen et al. (1998) found reduced nitrogen fixation in burned plots compared to unburned plots, but the difference was not significant. There were, likewise, no differences in nitrogen fixation between burned and unburned plots two years following a burn in a creosote bush (*Larrea divaricata*) grassland north of El Paso, Texas (Johansen et al. 1998).

The absence of significant and/or sustained reductions in nitrogen fixation in the present study as well as in others may be related to the presence of heterotrophic bacteria which can also fix nitrogen (Klubek and Skujiņš 1980, Jeffries et al. 1992). Heterotrophic bacteria are not dependent on sunlight like the photoautotrophic cyanobacteria. They can live below the surface, and are less likely to be damaged by intense surface heat.
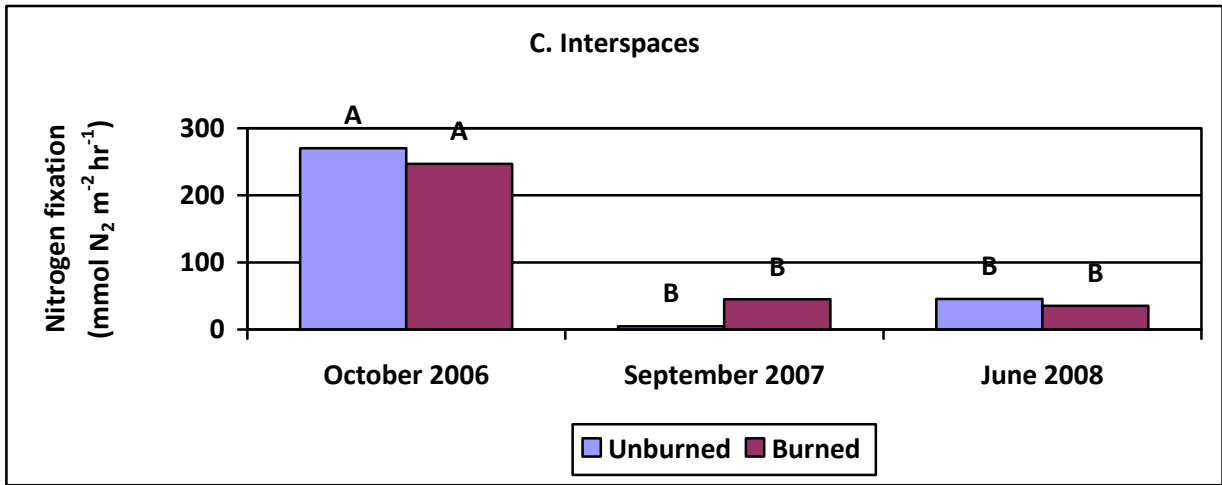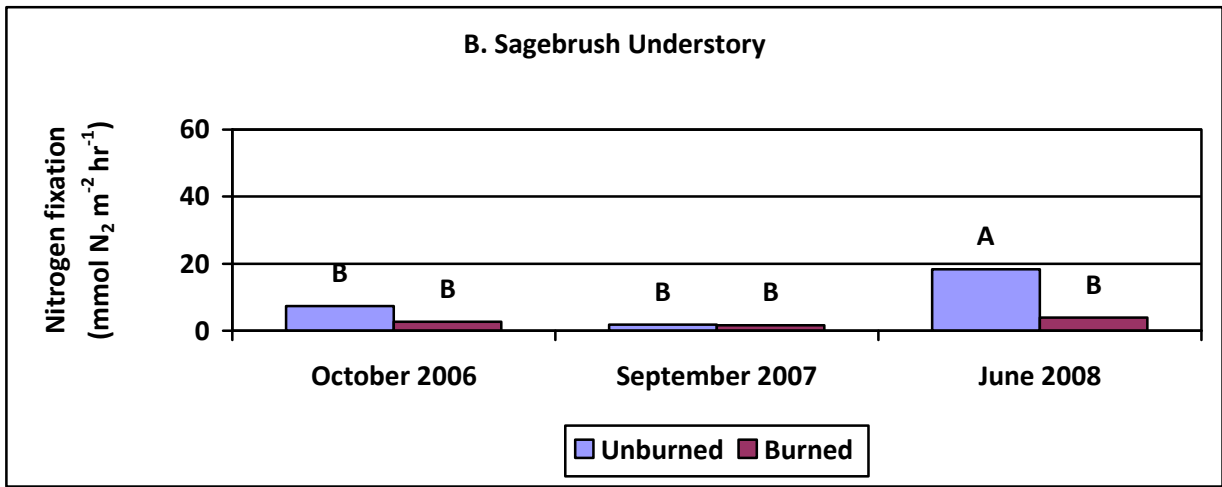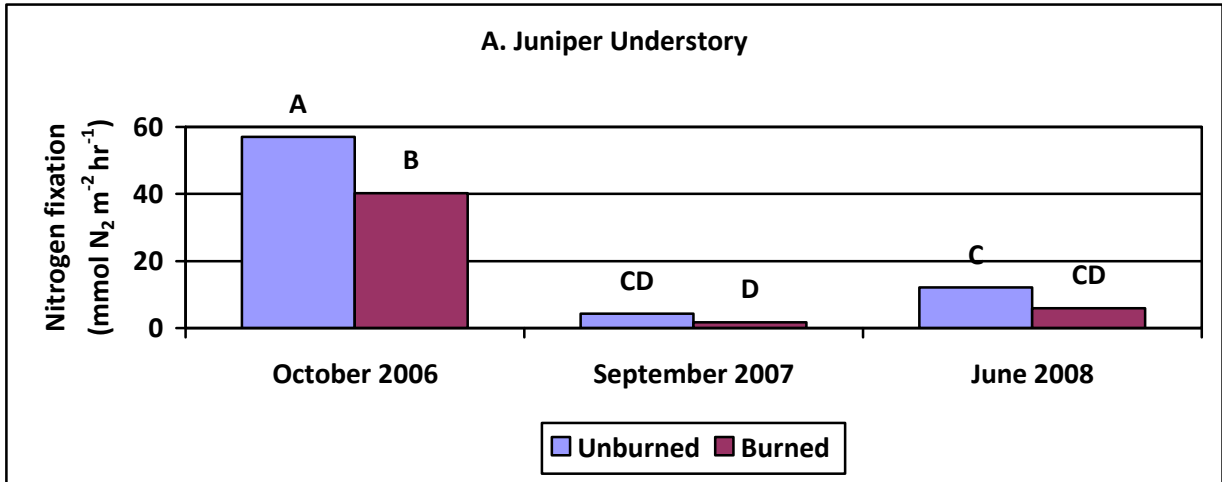
Figure 12. Nitrogen fixation (mmol N_2 m^{-2} h^{-1}) in mineral soil in unburned and burned juniper understory plots (A), sagebrush understory plots (B), and interspace plots (C) following a prescribed burn south of Tooele, Utah on 05 October 2006. Bars with the same letter within a vegetation patch type are not significantly different at α=0.05.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Mosses were rare beneath juniper trees and were unaffected by the prescribed burn, but the burn reduced the cover of mosses beneath sagebrush and in the shrub interspaces. Lichens were uncommon beneath the juniper and sagebrush. They were more common in the shrub interspaces, but because the fire was spotty and of low intensity in the interspaces, the impact on lichens was minimal.

The burn reduced the biomass and diversity of green algae and cyanobacteria under juniper and sagebrush, but these groups were unaffected in the shrub interspaces. This conclusion was confirmed by measuring the density of green algae and cyanobacteria which also showed a significant decline in the soil beneath juniper and sagebrush.

Nitrogen fixation was significantly reduced under juniper trees but not under the sagebrush or in the interspaces. Nitrogen fixation was approximately an order of magnitude greater in the shrub interspaces compared to beneath the juniper and sagebrush. Because the interspaces were not greatly affected by the burn itself, there was no significant impact on nitrogen fixation there.

In general, it appears that, while the burn negatively affected some biological soil crust components in some parts of the early successional stage of the juniper woodland, the overall impact of low intensity fire on biological soil crusts in juniper woodlands is of minimal concern. If the intent of burning is a reduction in juniper, burning of early successional juniper woodland is appropriate because most affected trees were killed. Control of sagebrush can likewise be accomplished by low intensity, cool season fires without serious damage to the biological soil crust. Due to the spotty nature of the fire in the shrub interspaces, intact biological soil crusts may provide algal inoculants to re-colonize the soil in the juniper and sagebrush vegetation patch types which were more affected by the fire. These data imply that intense fires should be avoided due to the potential for greater encroachment into the shrub interspaces which contain the best developed biological soil crusts. This information, plus the fact that late successional juniper woodlands are difficult to burn, suggests that burning of early succession juniper may a preferred method to control juniper encroachment on western rangelands

ACKNOWLEDGEMENTS

LITERATURE CITED

Antos, J.A., B. McCune and C. Bara. 1983. The effect of fire on an ungrazed western Montana grassland. American Midland Naturalist 110:354-364

Barney, M.A. and N.C. Frischknecht. 1974. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. Journal of Range Management 27:91-96

Bell, R.A. and M.R. Sommerfield. 1987. Algal biomass and primary production within a temperate zone sandstone. American Journal of Botany 74:294-297

Belnap, J. 2001. Biological soil crusts and wind erosion. Pages 339-347. In: J. Belnap and O.L. Lange (eds), Biological Soil Crusts: Structure, Function, and Management. Springer-Verlag, Heidelberg

Belnap, J., B. Büdel and O.L. Lange. 2001a. Biological soil crusts: characteristics and distribution. Pages 3-30. In: J. Belnap and O.L. Lange (eds), Biological Soil Crusts: Structure, Function, and Management. Springer-Verlag, Heidelberg

Belnap,J. R. Prasse and K.T. Harper. 2001b. Influence of biological soil crusts on soil environments and vascular plants. Pages 281-300. In: J. Belnap and O.L. Lange (eds), Biological Soil Crusts: Structure, Function, and Management. Springer-Verlag, Heidelberg

Bowker, M.A., J. Belnap, R. Rosentreter and B. Graham. 2004. Wildfire- resistant biological soil crusts and fire-induced loss of soil stability in Palouse prairies, USA. Applied Soil Ecology 26:41-52

Buckman, R.E. and G.L. Wolters. 1987. Multi-resource management of pinyon-juniper woodlands. Pages 1-4. In: R.L.Everett (compiler), Proceedings – Pinyon-Juniper Conference. USDA Forest Service General Technical Report INT-215

Bunting, S.C. 1987. Use of prescribed burning in juniper and pinyon-juniper woodlands. Pages 141-144. In: R.L. Everett (compiler), Proceedings – Pinyon-Juniper Conference. USDA Forest Service General Technical Report INT-215

Burns, S.J. 1983. Nitrogen fixation and transformation in cryptogamic soil crusts as affected by disturbance. M.S. Thesis. Brigham Young University, Provo, Utah

Buttars, S.M., L.L. St. Clair, J.R. Johansen, J.C. Sray, M.C. Payne, B.L. Webb, R.E. Terry, B.K. Pendleton, and S.D. Warren. 1998. Pelletized cyanobacterial amendments: laboratory testing for survival, escapability, and nitrogen fixation. Arid Soil Research and Rehabilitation 12:165-178

Carmichael, W.W. 1986. Isolation, culture, and toxicity testing of toxic freshwater cyanobacteria (blue-green algae). Pages 1249-1262. In: V. Shilov (editor), Fundamental research in homogenous catalysis, Volume 3. Gordon & Breach, New York, NY.

Evans, R.D. and O.L. Lange. 2001. Biological soil crusts and ecosystem nitrogen and carbon dynamics. Pages 265-282. In: J. Belnap and O.L. Lange (eds), Biological Soil Crusts: Structure, Function and Management. Springer-Verlag, Heidelberg

Ford, P.L. and G.V. Johnson. 2006. Effects of dormant – vs. growing-season fire in shortgrass steppe: biological soil crust and perennial grass responses. Journal of Arid Environments 67:1-14

Hilty, J.H., D.J. Eldridge, R. Rosentreter, M.S. Wicklow-Howard and M. Pellant. 2004. Recovery of biological soil crusts following wildfire in Idaho. Journal of Range Management 57:89-96

Jeffries, D.L., J.M. Klopatek, S.O. Link and H. Bolton, Jr. 1992. Acetylene reduction by cryptogamic crusts from a blackbrush community as related to resaturation and dehydration. Soil Biology and Biochemistry 24:1101-1105

Johansen, J.R. 2001. Impacts of fire on biological soil crusts. Pages 385-397. In: J. Belnap and O.L. Lange (eds), Biological Soil Crusts: Structure, Function, and Management. Springer-Verlag, Heidelberg

Johansen, J.R. and S.R. Rushforth. 1985. Cryptogamic soil crusts: seasonal variation in algal populations in the Tintic Mountains, Juab County, Utah. Great Basin Naturalist 45:14-21

Johansen, J.R. and L.L. St. Clair. 1986. Cryptogamic soil crusts: recovery from grazing near Camp Floyd State Park, Utah, USA. Great Basin Naturalist 46:632-640.

Johansen, J.R., A. Javakul and S.R. Rushforth.1982. Effects of burning on the algal communities of a high desert soil near Wallsburg, Utah. Journal of Range Management 35:598-600

Johansen, J.R., L.L. St. Clair, B.L. Webb and G.T. Nebeker. 1984. Recovery patterns of cryptogamic soil crusts in desert rangelands following fire disturbance. Bryologist 87:238-243

Johansen, J.R., J. Ashley and W.R. Rayburn. 1993. Effects of rangefire on soil algal crusts in semiarid shrub-steppe of the lower Columbia Basin and their subsequent recovery. Great Basin Naturalist 53:73-88.

Johansen, J.R., L.L. St. Clair, R.D. Evans, V.R. Flechtner, J. Balczon and B.L. Webb. 1998. Resilience of biological soil species to military training pressures: natural and stimulated recovery following disturbance. Final Report for contract DACA88-95-C-0015, submitted to the U.S. Army Construction Engineering Research Laboratory, Champaign, Illinois

Kasper, K.A. 1994. The effects of rangefire and trampling upon algal soil crusts of a greasewood community in the west desert of Utah. M.S. Thesis, John Carroll University, University Heights, OH

Klubek, B. and J. Skujiņš, 1980. Heterotrophic N_2-fixation in arid soil crusts. Soil Biology and Biochemistry 12:229-236

Ladyman, J.A.R. and E. Muldavin. 1996. Terrestrial cryptogams of pinyon-juniper woodlands in the southwestern United States: a review. USDA Forest Service, General Technical Report RM-GTR-280

Martin, R.E. 1978. Fire manipulation and effects in western juniper (*Juniperus occidentalis* Hook.). Pages 121-136. In: Proceedings – Western Juniper Ecology and Management Workshop. USDA Forest Service, General Technical Report PNW-74

Neuenschwander, L. F. 1980. Broadcast burning of sagebrush in the winter. Journal of Range Management. 333: 233-236

Ponzetti, J.M., B. McCune and D.A. Pyke. 2007. Biotic soil crusts in relation to topography, cheatgrass and fire in the Columbia Basin, Washington. The Bryologist 110:706-722

Rosentreter, R. and J. Belnap. 2001. Biological soil crusts of North America. Pages 31-50. In: J. Belnap and O.L. Lange (eds), Biological Soil Crusts: Structure, Function, and Management. Springer-Verlag, Heidelberg

Rychert, R.C. 2002. Assessment of cryptobiotic crust recovery. Western North American Naturalist 62:223-227

Schulten, J.A. 1985. The effects of burning on the soil lichen community of a sand prairie. Bryology 88:110-114

Springfield, H. W. 1976. Characteristics and management of Southwestern pinyon-juniper ranges: the status of our knowledge. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station Research Paper RM-160. Fort Collins, CO

Tchan, Y.T. 1952. Fluorescence microscopy for the study of soil algae. Proceedings of the Linnean Society of New South Wales 77:265-269

Terry, R.E. and V.D. Jolley. 1994. Nitrogenase activity is required for the activation of iron-stress response in iron-inefficient T203 soybean. Journal of Plant Nutrition 17:1417-1428

US Department of Agriculture. 2008. Web soil survey. http://websoilsurvey.nrcs.usda.gov/app/ Website viewed 30 September 2008

Wambolt, CL. and G.F. Payne, Gene. 1986. An 18-year comparison of control methods for Wyoming big sagebrush in southwestern Montana. Journal of Range Management. 39: 314-319

Warren, S.D. 2001a. Synopsis: influence of biological soil crusts on arid land hydrology and soil stability. Pages 351-362. In: J. Belnap and O.L. Lange (eds), Biological Soil Crusts: Structure, Function, and Management. Springer-Verlag, Heidelberg

Warren, S.D. 2001b. Biological soil crusts and hydrology in North American deserts. Pages 327-337. In: J. Belnap and O.L. Lange (eds), Biological Soil Crusts: Structure, Function, and Management. Springer-Verlag, Heidelberg

Western Regional Climate Center. 2008. http://www.wrcc.dri.edu/ Website viewed 30 September 2008

Wirth, T.A. and D.A. Pyke. 2003. Restoring forbs for sage grouse habitat: fire, microsites, and establishment methods. Restoration Ecology 11:370-377

Wrobleski, D.W. and J.B. Kauffman. 2003. Initial effects of prescribed fire on morphology, abundance, and phenology of forbs in big sagebrush communities in Southeastern Oregon. Restoration Ecology 11:82-90