AN ABSTRACT OF THE THESIS OF

Troy A. Wirth for the degree of Master of Science in Rangeland Resources and minor in Wildlife Science Presented on Febuary 29th, 2000. Title: Emergence, Survival and Reproduction of Three species of Forbs Important to Sage Grouse Nutrition in Response to Fire, Microsite and Method of Establishment

Abstract Approved

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David Pyke

Since settlement of the Intermountain West, sage grouse abundance and productivity has declined and their range has decreased. The decline of sage grouse populations is primarily due to permanent loss and degradation of sagebrush-grassland habitat. Recently, several studies have shown that sage grouse productivity may be limited by the availability of certain preferred, highly nutritious forb species that have also declined within sagebrush ecosystems of the Intermountain West.

During the spring and summer, forbs are extremely important in maintaining the nutritional status and productivity of pre-laying hens and growth and survival of rapidly growing chicks. Researchers studying sage grouse have suggested several methods for restoring forbs in depleted sage grouse habitat. Among the methods proposed are prescribed fires that produce small mosaics of burned and unburned patches on the landscape. For this to occur, an adequate pre-burn forb community must exist in the location of the fire. In areas without adequate pre-burn forb communites, forbs must re-seed naturally or be revegetated. The purpose of this study was to determine the suit

ability of three species of forbs for revegetation projects where improving sage grouse habitat is a goal. Species suitability was determined by evaluating the emergence, survival and reproduction of *Crepis modocensis* Greene, *Crepis occidentalis* Nutt. and *Astragalus purshii* in response to method of establishment (seeding or transplanting), pre-establishment treatment (burned or unburned), and microsite (mound or interspace). Four prescription burns of sagebrush grassland were set at the United States Fish and Wildlife Service Hart Mountain National Antelope Refuge, Oregon. After burning, one experimental plot was randomly located within each burned and unburned site. Of the seeds planted in 1997, *A. purshii* had the lowest emergence (8%) of all three species. Both *Crepis* species had similar overall emergence (38%). Significantly more *Crepis* seedlings emerged from shrub mounds in unburned areas (50%) than in any other fire by microsite treatment (33 to 36%). Significantly more *A. purshii* emerged in the burned interspace (10.9) compared to the burned mounds (3.5). Nearly twice as many emerging *Crepis* seedlings survived in the burned areas as opposed to unburned areas ($P<0.01$). This resulted in more plant establishment in burned mounds despite higher emergence in unburned mounds. Microsite also significantly affected survival of *Crepis* seedlings ($P<0.01$). Approximately 10% more *Crepis* seedlings survived in mounds compared to interspaces. *A. purshii* seedlings also survived better in burned areas ($P=0.06$), but had no differential response to microsite. Fire enhanced survival of both *Crepis* and *A. purshii* transplants ($P=0.08$ and $P=0.001$), although, transplanting did not enhance plant establishment over seedings. Therefore, I conclude that revegetation of sage grouse habitat with *Crepis* species is a viable option given its high germinability, favorable response to fire and wide distribution.

Emergence, Survival and Reproduction of Three Species of Forbs Important to Sage Grouse Nutrition in Response to Fire, Microsite and Method of Establishment

By

Troy A. Wirth

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CONTRIBUTION OF AUTHORS

Dr. David Pyke was involved with the design and analysis of this experiment as well as the writing of this manuscript.

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Emergence, Survival and Reproduction of Three Species of Forbs Important to Sage Grouse Nutrition in Response to Fire, Microsite and Method of Establishment

INTRODUCTION

Sage Grouse Abundance and Habitat

The sage grouse (*Centrocercus urophasianus* Bonaparte) is a native upland gamebird found in the Intermountain West. Currently, there are two subspecies of sage grouse recognized by the American Ornithologists Union (AOU). These are the eastern (*C. u*. ssp. *urophasianus* Bonaparte) and western subspecies (*C. u*. ssp. *phaios* Aldrich). Sage grouse are sagebrush (*Artemisia* L. sp.) obligates; they are found only in areas dominated by this plant.

Since settlement of the Intermountain West, sage grouse abundance and productivity has declined and their range has decreased (Dalke et al. 1963, Crawford & Lutz 1985). The western subspecies was listed as a candidate for threatened and endangered status in 1985 by the United States Department of the Interior (Drut 1994) and subsequently reduced to a species of concern. Currently, remnant populations of sage grouse in the state of Washington as well as the Gunnison sage grouse in Colorado have been formally petitioned under the Endangered Species Act. Remaining populations of sage grouse are expected to be petitioned for listing in 2000. The state of Oregon has designated the sage grouse as a sensitive species.

The decline of sage grouse populations is primarily due to permanent loss and degradation of habitat. Large tracts of suitable sage grouse habitat have been lost due to removal of sagebrush (Drut 1994). The habitat that remains has been

degraded by reseeding with exotic grasses, invasion of exotic annual plants, fire suppression, and historical overgrazing by livestock (Drut 1994).

Before settlement of the Intermountain West in the 1840's, much of the sagebrush steppe consisted of "open stands of shrubs with a strong component of long-lived perennial grasses and forbs in the understory" (Miller et al. 1994). Since settlement, the abundance of perennial grasses and forbs in these communities has decreased while the abundance and density of sagebrush has increased. Historical overgrazing and fire suppression are the primary causes of this shift in the plant community (Laycock 1967, Eddleman 1989, Winward 1991, Miller et al. 1994).

Sage Grouse Nutrition

During fall and winter, when grasses and forbs are dormant and insects are scarce, sage grouse depend wholly upon sagebrush for food. During the spring, their diet changes to reflect the availability of insects and herbaceous vegetation in their environment, primarily beetles and forbs (Klebenow and Gray 1968). In spring and summer, sage grouse movements and habitat use are affected by the availability of forbs. In areas where forbs are abundant, broods will remain near their nesting sites until forbs become unavailable (Autenrieth 1981). As desiccation of forbs occurs in upland areas, sage grouse move toward more mesic meadows, lakebeds and springs where forbs are still green.

Forbs contain higher amounts of protein, calcium and phosphorous than sagebrush. During the pre-laying and chick-rearing periods, forbs are extremely important in maintaining the nutritional status and productivity of pre-laying hens, and growth and survival of rapidly growing chicks (Barnett and Crawford 1994,

Drut et al. 1994). In feeding trials, Johnson & Boyce (1990) showed that decreased nutritional intake resulted in higher mortality of sage grouse chicks. Also, two recent studies have shown that adult sage grouse productivity is lower in areas where highly nutritious foods (i.e. forbs and insects) are less abundant (Barnett & Crawford 1994, Drut et al. 1994). These studies compared abundance of foods important to sage grouse chicks and pre-laying hens at two ecological sites in eastern Oregon (Hart Mountain and Jackass Creek) that differed in long-term sage grouse productivity. Hart Mountain averaged 1.6 sage grouse chicks/hen and Jackass Creek averaged 0.9 chicks/hen from 1985 to 1992. At Hart Mountain, there were significantly greater amounts of forbs, insects and grasses than at the Jackass Creek site. These studies also determined the genera of forbs selected by sage grouse with greater frequency than their occurrence in the environment. Plants most consumed by pre-laying hens based on frequency and mass were *Crepis* L. spp., *Astragalus purshii* Dougl. ex Hook., *Phlox longifolia* Nutt. and *Lomatium* Raf. spp. (Barnett & Crawford 1994). Sage grouse chicks most frequently consumed *Crepis* L. spp., *Trifolium* L. spp., *Astragalus* L. spp., *Taraxacum* G. H. Weber ex Wiggers, *Agoseris* Raf. spp. and *Microsteris gracilis* (Hook.) Greene. (Drut et al. 1994).

Sage Grouse Habitat Management

Many techniques to manage semi-arid lands for sage grouse habitat in the Great Basin have been developed (Autenrieth 1981). Fire and herbicides have been used to reduce sagebrush density and allow establishment or recovery of perennial forbs and grasses. Fire is effective at reducing sagebrush densities while increasing forb biomass and cover until shrub dominance is re-established (Pechanec et al.

1954, Harniss and Murray 1973). Forb response to fire is dependent on plant morphology and the timing and intensity of burning (Bunting et al. 1988, Young 1983, Wright 1982). Herbicides have the potential to damage forb populations if applied incorrectly and may have other undesirable effects such as persistence in the environment and toxicity to other life forms.

Revegetation with non-native grasses and forbs has been used to increase available foods for sage grouse, but no research has been done to confirm that non-native forbs are preferred and fulfill the nutritional requirements of sage grouse. Sage grouse require sagebrush for cover, nesting, and food. Fire, herbicides, and traditional methods of revegetation sacrifice one habitat requirement, sagebrush, to satisfy another, forbs. Grazing management is employed to avoid disturbance of sage grouse leks and nests. Cattle outcompete sage grouse for forage especially in mesic areas where they are more likely to interact. Grazing cattle at appropriate times and locations can reduce harmful cattle-grouse interactions (Autenrieth 1981).

Researchers studying sage grouse have suggested several methods for restoring depleted sage grouse habitat (Autenrieth 1981, Barnett & Crawford 1994, Drut 1994, Welch et al. 1990). Among the methods proposed are prescribed fires that produce small mosaics of burned and unburned patches on the landscape (Crawford et al. 1992). With this method, forbs would increase in burned areas when released from competition with sagebrush, while leaving nearby unburned patches for sage grouse nesting and cover. For this to occur, an adequate pre-burn forb community must exist in the location of the fire. In areas without adequate pre-burn forb communities, forbs must re-seed naturally or be revegetated.

Factors Affecting Forb Establishment

Microtopography plays an important role in the establishment of plants by providing safe sites for germination and growth. Blackburn (1975) discussed the biophysical characteristics of the two most common microsites in semi-arid regions of the Great Basin. These are coppice dunes, which are found underneath canopies of sagebrush, and dune playettes, which are found in the areas between sagebrush canopies. Eckert et al. (1986a) refined the microtopography concept and related it to plant establishment. They defined four microsites that occur in *A. tridentata* ssp. *wyomingensis* Beetle and Young plant communities in the northern Great Basin. These microsites are coppices, coppice benches, intercoppice microplains, and playettes, each with a unique soil surface type. Coppices consist of conical-raised areas in topography and are found primarily under shrub canopies. Coppice benches are the sloping areas next to coppices while intercoppice microplains are flat areas next to coppice benches. Playettes consist of slightly depressed or flat areas and have the lowest elevation of the four microtopographic areas. Eckert et al. (1986b) found that establishment of desirable species was highest on the coppices and coppice benches and suggested that areas with higher percentages of these microsites may be more successful in natural revegetation.

Because the coarser scale microtopography described by Blackburn (1975) is easier to distinguish than the four microsites described by Eckert (1986a) after a fire, my study focused on mounds (coppice dunes) and interspaces (dune interspaces). Mounds encompass both coppices and coppice benches, while interspaces encompass the intercoppice microplains and playettes described by Eckert et al. (1986a). Mounds have slightly higher microtopography, higher veg-

etative cover, increased water infiltration, cooler temperatures, and lower levels of solar radiation than interspaces. Doescher et al. (1984) found that soil from mounds in high grass, low shrub sites contained twice the nitrogen and organic matter than interspace areas. Furthermore, phosphorous, potassium, calcium and magnesium were also higher on mounds than interspaces. Magnesium and pH did not differ among microsites in the upper 20 cm of the soil. However, magnesium in deep horizons was significantly higher in the interspace than in the mound. Significantly higher amounts of available nutrients within mounds may allow higher seedling establishment in these microsites.

PURPOSE

The purpose of this study was to determine the suitability of three species (*Crepis modocensis* Greene, *Crepis occidentalis* Nutt. and *Astragalus purshii* Dougl. ex Hook. var. *tinctus* M.E. Jones) for revegetation projects where improving sage grouse habitat is a goal. Species suitability was determined by evaluating the emergence, survival and reproduction in response to method of establishment (seeding or transplanting), pre-establishment treatment (burned or unburned), and microsite (mound or interspace).

I hypothesized that strategic placement of seeds or transplants in mound microsites during a revegetation effort would significantly improve plant establishment. Broadcast seeding and drilling are two techniques commonly used for grass-forb mixtures; however, they distribute seeds in regular patterns across the landscape. Since native forb seed is expensive and often commercially unavailable, this approach may not be the most cost-effective method of establishment because many seeds will land on unfavorable microsites. Planting seeds or transplants in microsites with favorable environmental factors may maximize the establishment of native forb populations.

STUDY SITES

The U. S. Fish and Wildlife Service (USFWS) chose eight similar 400-hectare study areas at Hart Mountain National Antelope Refuge in southeastern Oregon that are located within current and historical sage grouse range (Fig. 1). The climate in this region is semi-arid, temperate and continental, with hot, dry summers, and cold, moist winters. Annual precipitation ranges from 203 to 305 mm per year. The USFWS excluded livestock grazing in December 1990 (USFWS 1994); however, wild horses, pronghorn antelope, mule deer and small mammals had free access to all sites.

All sites occur on the clayey 10-12 inch ecological site (USDA-NRCS 1998). The potential natural plant community for this ecological site is Wyoming big sagebrush – bluebunch wheatgrass association, with approximately 75% grass, 10% forb and 15% shrub composition by weight. Current dominant plants at the site are *Artemisia tridentata* ssp. *wyomingensis* associated primarily with perennial grasses, *Poa secunda* J. Presl., *Elymus elymoides* (Raf.) Swezey and to a lesser extent *Achnatherum thurberianum* (Piper) Barkworth and *Pseudoroegneria spicata* (Pursh) A. Löve. Some meadows do occur at the sites and are dominated by *Artemisia arbuscula* Nutt., *Poa secunda* and associated forbs, but these areas were not included in this study.

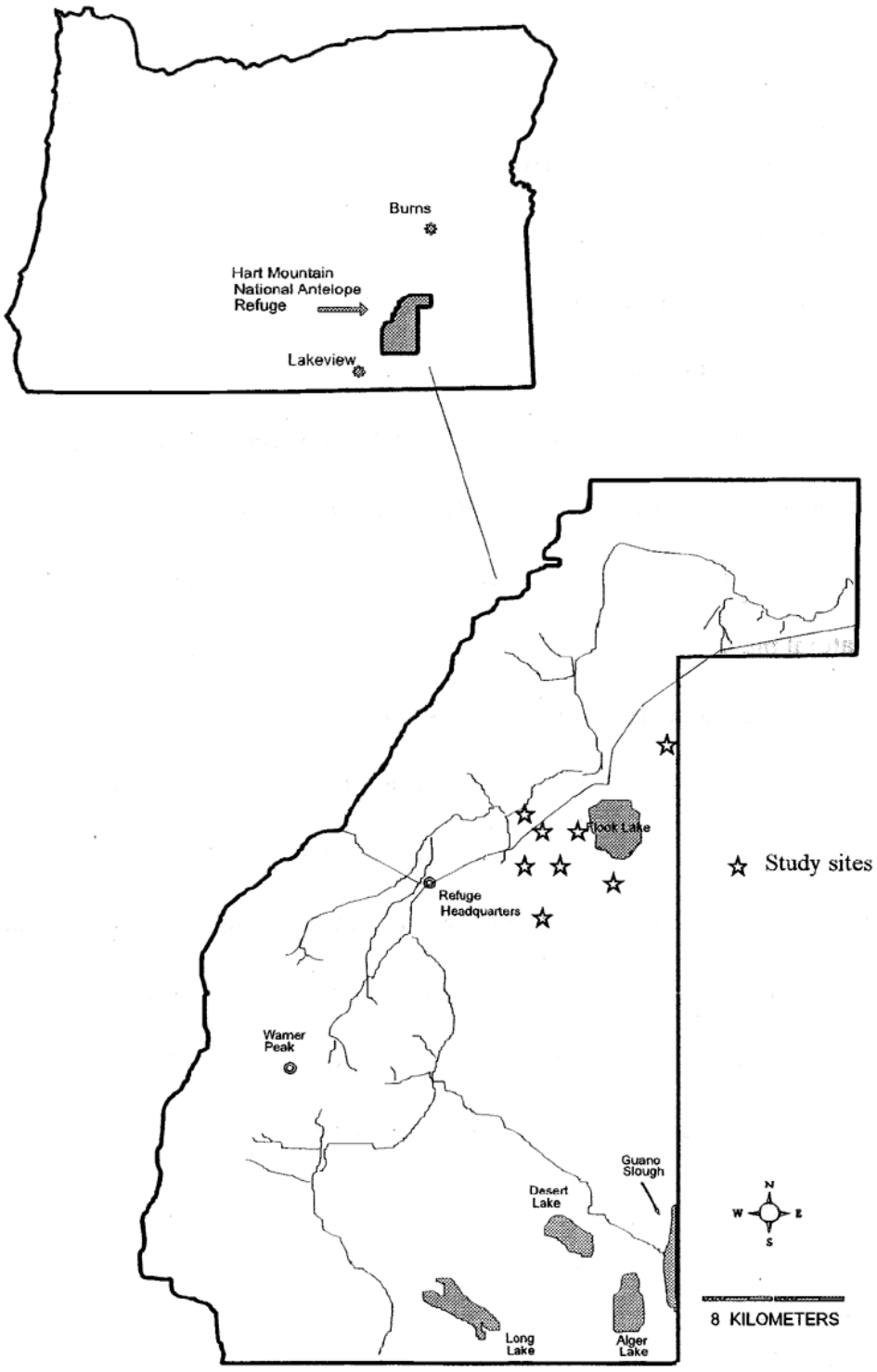

Figure 1. Location of Hart Mountain National Antelope Refuge study sites, Lake County, Oregon. Map courtesy of OSU Gamebird Research Program.

MATERIALS AND METHODS

Prescribed Fires and Community Response

In autumn 1997, the USFWS randomly selected and burned four of the eight sites. Fires were ignited by two methods, drip torch (site 1) and helitorch (sites 2-4). Fire behavior varied among and within each fire due to differing weather conditions and the large size of treated areas.

I clipped, dried (60°C for 48 hours) and weighed pre- and post-burn fine fuel loads (herbaceous vegetation and litter) within 25 randomly located 20 x 50-cm plot frames (Table 1). Fire consumption of fine fuel (percentage consumed) was calculated as the difference between the average before- and after-fire biomass divided by the before–fire biomass multiplied by 100 (Table 1). I estimated sagebrush biomass per ha by harvesting five randomly selected whole plants at each site before the fires and multiplied the combined average by the sagebrush density at each site. Sagebrush density (plants/ha) was estimated using the point-centered-quarter method (n=50) (Pieper 1973).

Immediately before each fire, I took ten samples per site of both the understory and overstory vegetation to determine pre-ignition moisture content (Table 1). These samples were placed in paper bags and then sealed in airtight plastic bags to avoid loss of moisture, weighed, and then dried at 60°C for 48 hours and re-weighed to determine moisture content.

Table 1. Mean sagebrush density (plants/ha), biomass (kg/ha), pre and post-fire understory biomass (kg/ha), and overstory and understory moisture (%) at the four burned sites at Hart Mountain National Antelope Refuge in the autumn of 1997. Figures in parentheses are standard errors. The average sagebrush plant weighed 0.36 kg.

Site	Flame Length	Flame Height	Flame Depth	Flame Angle	Flame Spread	Residence Time	Intensity	Heat/Area
1	4.0	2.7	2.7	44.3	.10	153	9,128.93	91,289
2	4.2	3.25	4.0	52.5	.07	92.5	9,422.68	123,982
3	4.4	3.3	7.8	4.0	.20	49	9,897.21	52,090
4	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data

Fire behavior data at each site were difficult to obtain due to the size of the fire, smoke, topography and fire hazard. Fire behavior data were collected when possible, but these data are subject to bias by the location of the observer, wind at the time of observation, lighting technique for that particular "run" of flame and other factors. During the fire, observers visually estimated flame height, depth, angle and length ($\mathbf{F_L}$). Rate of spread (**R**) was estimated by timing how long the fire took to move a specific distance, or by the visual estimates of experienced observers (Table 2). Fireline intensity (**I,** kW/m^2) and heat per unit area ($\mathbf{H_A}$, kJ/ m^2) were estimated according to Rothermel & Deeming (1980) with the following equations:

$$\mathbf{I} = 258\ \mathbf{F_L}^{2.17},$$

$$\mathbf{H_A} = 60\mathbf{I} / \mathbf{R}$$

Site	Brush Density	Brush Biomass	Pre-fire Understory	Post-fire Understory	% Consumed	Overstory Moisture	Understory Moisture
1	29,091	10,482	1406 (365)	562 (281)	60.0%	20.86 (1.67)	4.27 (0.09)
2	16,063	5,788	1855 (228)	126 (15)	93.2%	22.53 (3.04)	4.15 (0.63)
3	17,308	6,236	1677 (279)	153 (21)	90.8%	24.23 (1.30)	4.60 (0.49)
4	17,655	6,361	1262 (132)	328 (71)	74.0%	20.05 (1.55)	6.46 (0.58)

Table 2. Mean flame length (m), height (m), depth (m), angle (%), spread (m/s), residence time (s), intensity (kW/m^2), and heat/area (kJ/m^2) of each fire at Hart Mountain National Antelope Refuge, OR in autumn 1997.

All four fires were head fires. Site one was ignited shortly after 12:00 on 23 September 1997. The relative humidity at the time of ignition was 19-21%, windspeed was 11.3 – 16.1 km/h from the southeast and the temperature was 26.6 °C. Due to an accident involving the transport of helicopter fuel to the helipad in Lakeview, OR, this fire was ignited by driptorch only. The fire carried little and required constant re-lighting. Site two was ignited at 15:20 on 24 September 1997 by helitorch. The relative humidity at the time of ignition was 17% and windspeed was 3.2 to 8.0 km/h from the west. The fire at site two carried more than at site one due to decreased humidity and the arrival of the helitorch. This fire had the highest $\mathbf{H_A}$ of all four fires. No burning took place on 25 through 27 September 1997 due to adverse weather conditions. Site three was ignited at noon on 28 September 1997. At the time of ignition, windspeed was 8.0 to 11.3 km/h from the east, relative humidity was 24% and the temperature was 18.9 °C. The fire at site three was relatively intense, fast moving, and carried well. Site four was ignited at 14:30 on 28 September 1997. At site four, relative humidity was 18%, wind speed was 8.0 to 11.3 km/h from the east and the temperature was 23.3 °C. Fire behavior at site four was not obtained due to high fire hazards, however, site four appeared to burn similar to site three.

I estimated species composition by the Daubenmire (1959) canopy coverage method modified by locating 50 quadrats individually and randomly at each site. Coverage data were collected for each plant species in June 1997 before burning. Eight, 1-ha experimental plots were established in September 1997. Coverage was measured at the 1-ha experimental plots in July 1998 and 1999. Because pre-fire data were collected in larger areas than

post-fire data, direct comparisons should not be made between years, but general trends can be implied as to effects of fire on species composition (Table 3). A list of species cover and composition by site is given in appendix F.

Table 3. Shrub, grass and forb cover (%) and composition (%) at the eight locations in 1997, 1998, and 1999 at Hart Mountain National Anetlope Refuge, OR

	Cover			Composition		
1997	**Shrub**	**Grass**	**Forb**	**Shrub**	**Grass**	**Forb**
Site 1 - Burned	33.8	10.6	11.5	60.6	18.9	20.5
Site 2 - Burned	24.2	16.6	8.0	49.6	34.0	16.4
Site 3 - Burned	30.1	12.8	8.8	58.0	25.0	17.0
Site 4 - Burned	21.7	8.9	9.1	54.7	22.4	23.0
Site 5 - Unburned	22.2	11.8	15.9	44.5	23.6	31.9
Site 6 - Unburned	20.6	9.7	7.2	54.9	25.8	19.3
Site 7 - Unburned	20.0	11.6	8.0	50.5	29.2	20.2
Site 8 – Unburned	27.9	9.9	11.4	56.5	20.3	23.3
	Cover			**Composition**		
1998	**Shrub**	**Grass**	**Forb**	**Shrub**	**Grass**	**Forb**
Site 1 - Burned	0.2	6.9	37.2	0.5	15.7	84.3
Site 2 - Burned	0.0	8.7	39.8	0.0	17.9	82.1
Site 3 - Burned	0.2	8.1	42.9	0.2	15.8	84.0
Site 4 - Burned	0.0	24.5	23.2	0.0	51.3	48.7
Site 5 - Unburned	22.4	9.4	26.1	38.7	16.3	45.0
Site 6 - Unburned	27.2	14.8	11.3	51.0	27.7	21.3
Site 7 - Unburned	18.5	18.3	15.2	35.5	35.2	29.3
Site 8 - Unburned	31.2	8.1	8.9	64.8	16.8	18.4
	Cover			**Composition**		
1999	**Shrub**	**Grass**	**Forb**	**Shrub**	**Grass**	**Forb**
Site 1 - Burned	0.0	10.0	42.0	0.0	19.2	80.8
Site 2 - Burned	0.0	17.5	38.2	0.0	31.4	68.6
Site 3 - Burned	0.3	19.0	64.6	0.6	35.3	64.1
Site 4 - Burned	0.3	34.6	7.6	0.6	82.0	18.0
Site 5 - Unburned	20.4	14.2	16.6	39.9	27.7	32.4
Site 6 - Unburned	19.3	16.4	8.2	44.0	37.4	18.5
Site 7 - Unburned	20.5	14.8	7.5	47.9	34.5	17.6
Site 8 - Unburned	28.1	8.7	4.9	67.4	20.8	11.8

Forb Restoration

I used a randomized block split-plot design for the forb restoration experiment (Fig. 2). After burning, one 1-ha (100 x 100m) experimental plot was randomly located within each of the eight original 400 ha sites, resulting in four burned and four unburned site replicates.

In late June 1997, I collected seeds of three forb species, *Crepis occidentalis*, *Crepis modocensis* and *Astragalus purshii* within 10 km of the sites. Seeds were collected to sample the highest amount of genetic diversity (Knapp and Rice 1994). In the laboratory I sorted viable seeds from nonviable seeds by fruit presence, size and color. For *Crepis occidentalis*, viable seeds were dark brown, firm, and visibly wider than nonviable seeds. Viable seeds of *Crepis modocensis* were firm, usually dark green, but some were light brown. There were three kinds of *A. purshii* seeds, green, brown and black. Green seeds were small and undeveloped while brown seeds were small and brittle. Only black seeds that were large compared to the green and brown seeds were selected for planting. The Oregon State University Seed Research Laboratory in Corvallis, OR conducted standard seed viability tests with tetrazolium chloride.

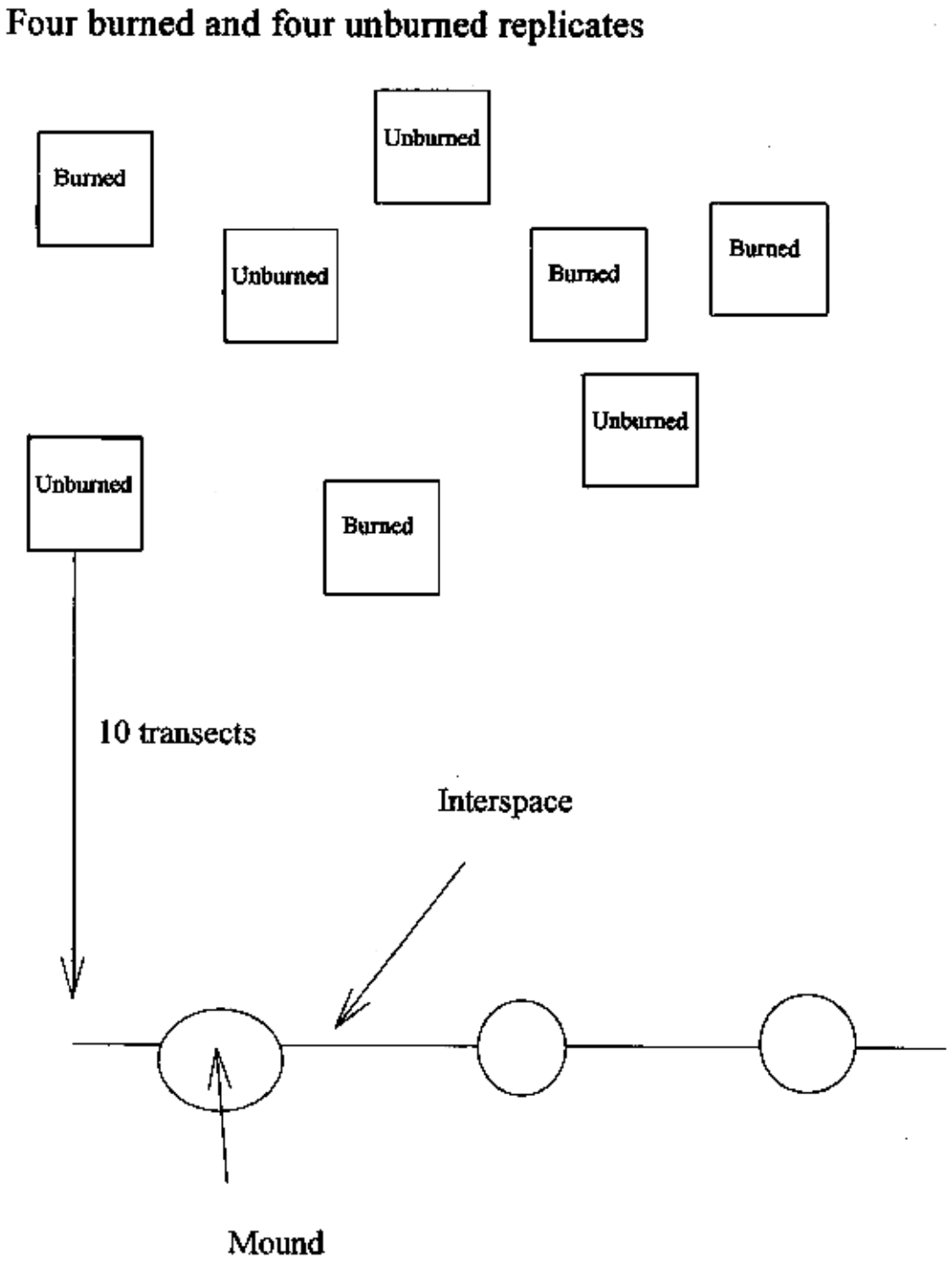

Figure 2. Experimental design of forb restoration project at Hart Mountain National Antelope Refuge

In October 1997, I sowed 250 seeds of each species at each site along 10, 80-m transects. Each transect was randomly located along and perpendicular to a 100-m baseline. At each location, one seed was planted 1 cm deep within alternating microsites, mounds and interspaces, as they occurred naturally along each transect. I randomized the species order along each transect. The distance of each seed along each transect baseline was recorded and marked by a nail 10 cm after each seed.

Monitoring for seedling emergence began on 21 March 1998 by checking the location of each planted seed along each transect. If the seedling emerged, I noted its survival status and placed a wire ring around the stem to facilitate relocation. Censuses occurred on 8 and 28 April, 19 May, 17 June, 7 and 28 July in 1998 and 17 April, 15 May, 15 June and 20 July in 1999.

Seedlings of each species were raised at Oregon State University during the winter of 1997/8. These seeds came from the same accession as those sown in the field in autumn 1997. All seeds underwent cold stratification while buried 1.0 cm deep in moist sand at 2.2° C for 6 weeks beginning in December 1997 and then were placed in a heated greenhouse (20 °C day/night) to germinate. When the cotyledon emerged from the sand, I transplanted the seedlings into styrofoam vent blocks (1.9-cm diameter by 12.7-cm deep) filled with a mixture of 30% potting soil and 70% loam. Transplants were grown for 10 weeks in the greenhouse and then placed in a cold frame for 3 weeks to harden before transplantation. I planted the seedlings into the field on 28 April 1998 and censused their survival status on the same dates as the seeded transects. Due to a limited number of *Crepis* transplants, only three burned and three unburned sites received transplants. Sites one, two, three, five, seven and eight received 50 transplants per *Crepis* species and

microsite. All sites received 50 transplants per microsite of *A. purshii.*

I analyzed establishment of emerged seedlings and transplants using two techniques. I tested for significant differences among treatments in emergence and proportional survival using analyses of variance (SAS, PROC MIXED; SAS Institute 1996). The ANOVA's for emergence compared the proportion of those plants that emerged by the second growing season (15 June 1999) in each treatment, while the ANOVA's for proportional survival compared the proportion of emerged plants that survived to the end of the second growing season (15 June 1999). These ANOVA's used individuals from all cohorts in each analysis. Full ANOVA tables for each analysis are presented in appendix G. The SAS MIXED procedure calculates population parameters based on density functions. Therefore, these ANOVA tables do not have some of the information normally given in ANOVA tables. Data for ANOVA's of *A. purshii* emergence and *Crepis* transplant survival were arcsin squareroot transformed because these mean proportions were below 0.3, resulting in non-normal distributions. Proportional emergence and survival in all other analyses were between 0.3 and 0.7 and transformation has little effect in this region (Steel et al. 1997). Back-transformed means are reported where appropriate.

Survival rates were compared among treatments for individuals from cohort 1 of each species using Peto and Peto's logrank test (Pyke and Thompson 1986, Hutchings et al. 1991). Cohort 1 consisted of plants emerging from seed before 21 March 1998. This cohort was the largest of any cohort with 72% and 68% of all emerging *Crepis* and *A. purshii* seedlings, respectively. This analysis generated an estimate of the daily risk of

mortality during each census period and treatment combination. The 95% confidence intervals around each rate for each treatment and census date were used to determine differences among treatments at each census period.

RESULTS

In 1998, there was above average precipitation, leading to a longer growing season than normal. In 1999, the growing season was shortened due to cold temperatures lasting farther into the spring than normal followed by very little precipitation. Although viability was high for the three species, emergence of *A. purshii* was approximately 10% that of the two *Crepis* species. Seed viability for both *Crepis* species was 93%, whereas for *A. purshii* it was 100%. Because of this large difference in emergence, *A. pur*shii was analyzed separately from the two *Crepis* species for both emergence and survival.

Emergence did not differ between the two species of *Crepis* regardless of fire and microsite treatments (P=0.87). The mound microsite was only an advantage for *Crepis* emergence in unburned sites (fire by microsite interaction, P<0.01, Fig. 3a). Emergence from all other treatments was statistically similar.

As with the *Crepis* species, I found a fire by microsite interaction for emergence of *A. purshii* seedlings (P=0.02), however, the microsite effect was opposite that of *Crepis*. Emergence of *A. purshii* was higher in the burned interspace compared with the burned mound (P=0.01 Fig 3b). All other comparisons did not differ statistically.

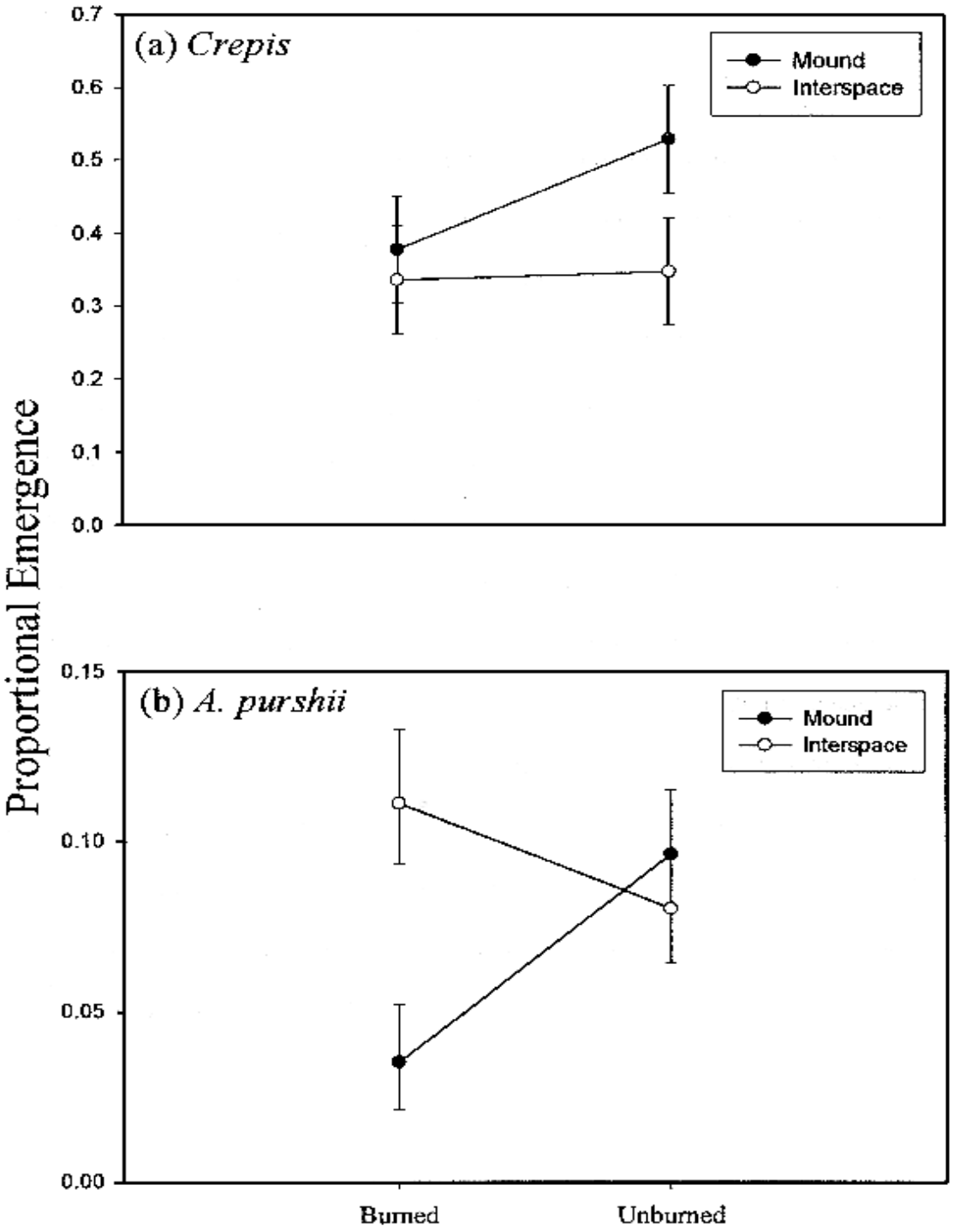

Figure 3. (a)Mean emergence (+- S.E.) of *Crepis occidentalis* and *C. modocensis* combined in response to fire and microsite and (b) mean emergence (+- S.E.) of *A. purshii* in response to fire and microsite

Table 4. Mean emergence and survival from seed and transplants (± 1 S.E.) at the end of the second growing season (July 1999) for all cohorts of plants emerging in four treatments at Hart Mountain National Antelope Refuge, OR

Autumn 1997 Emergence	**Burned Mound**	**Burned Interspace**	**Unburned Mound**	**Unburned Interspace**
C. modocensis	34.6 (7.8)	33.8 (7.8)	55.3 (7.8)	35.6 (7.8)
C. occidentalis	40.7 (7.8)	33.3 (7.8)	50.2 (7.8)	33.6 (7.8)
A. purshii	3.5 (+1.7,-1.4)	10.9 (+2.2,-1.8)	9.6 (+1.9,-1.9)	8.0 (+1.7,-1.6)
Autumn 1997 Seedling Survival	**Burned Mound**	**Burned Interspace**	**Unburned Mound**	**Unburned Interspace**
C. modocensis	60.0 (5.7)	46.1 (5.7)	38.1 (5.7)	25.7 (5.7)
C. occidentalis	62.6 (5.7)	53.6 (5.7)	34.3 (5.7)	24.9 (5.7)
A. purshii	39.8 (8.5)	44.3 (8.5)	26.0 (8.5)	18.5 (8.5)
Spring 1998 Transplant Survival	**Burned Mound**	**Burned Interspace**	**Unburned Mound**	**Unburned Interspace**
C. modocensis	14.9 (+4.6,-4.0)	6.6 (+3.2,-2.6)	4.9 (+2.8,-2.2)	2.0 (+1.9,-1.3)
C. occidentalis	22.4 (+5.5,-4.9)	15.2 (+4.6,-4.0)	9.7 (+3.8,-3.2)	8.1 (+3.5,-2.9)
A. purshii	50.5 (4.4)	50.7 (4.4)	16.0 (4.4)	18.5 (4.4)

Proportional survival of the two *Crepis* species emerging from seed was similar under all treatments (P=0.69). *Crepis* survival was higher in burned compared to unburned sites and was nearly 10% higher on mounds than interspaces (P<0.01 for each treatment, Figs. 4 and 5). There were no interactions among any treatments (P=0.29).

Survivorship of the first cohort of seeded *Crepis* differed during different census periods (*C. modocensis,* df=3, $\div^2$= 22.2, P<0.01; *C. occidentalis,* df=3, $\div^2$ =37.4, P<0.01). Generally, *Crepis* seedlings emerging from burned mounds had the highest mortality rates early in the growing season. However, the mortality risk of seedlings in other treatments, especially those in the interspace microsites, quickly surpassed those on the burned mounds (Figs. 6 & 7).

Burning was the only treatment that affected the proportional survival of *A.*

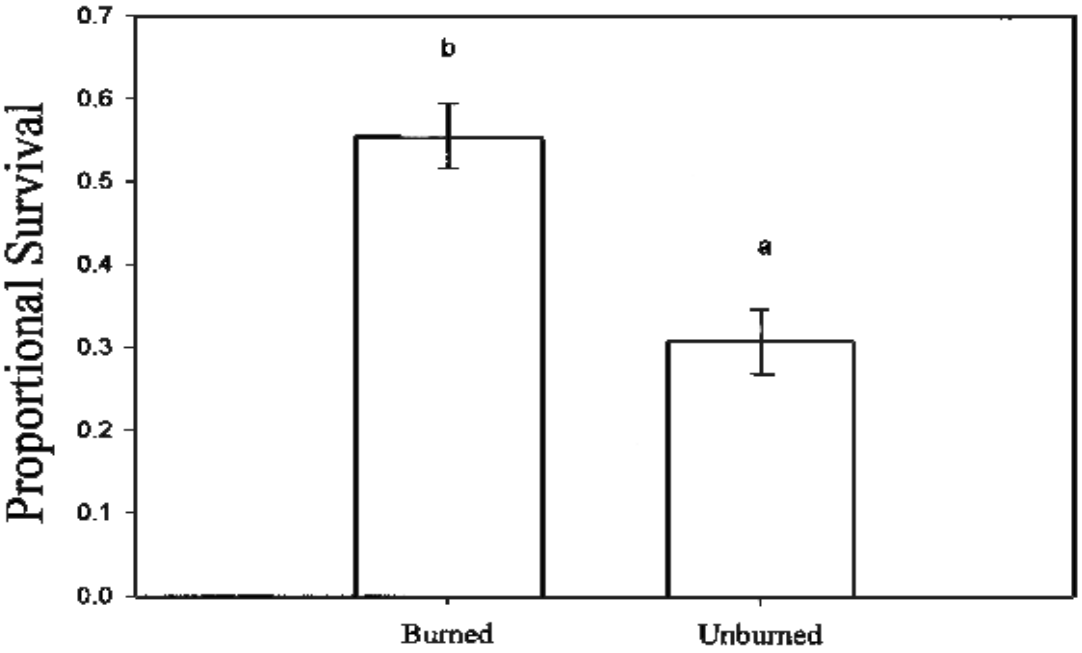

Figure 4. Mean proportional survital (+- S.E.) of combined emergent seelings of *Crepis occidentalis* and *C. modocensis* in response to fire. Different lower case letters represent statistically significant difference at P<0.05

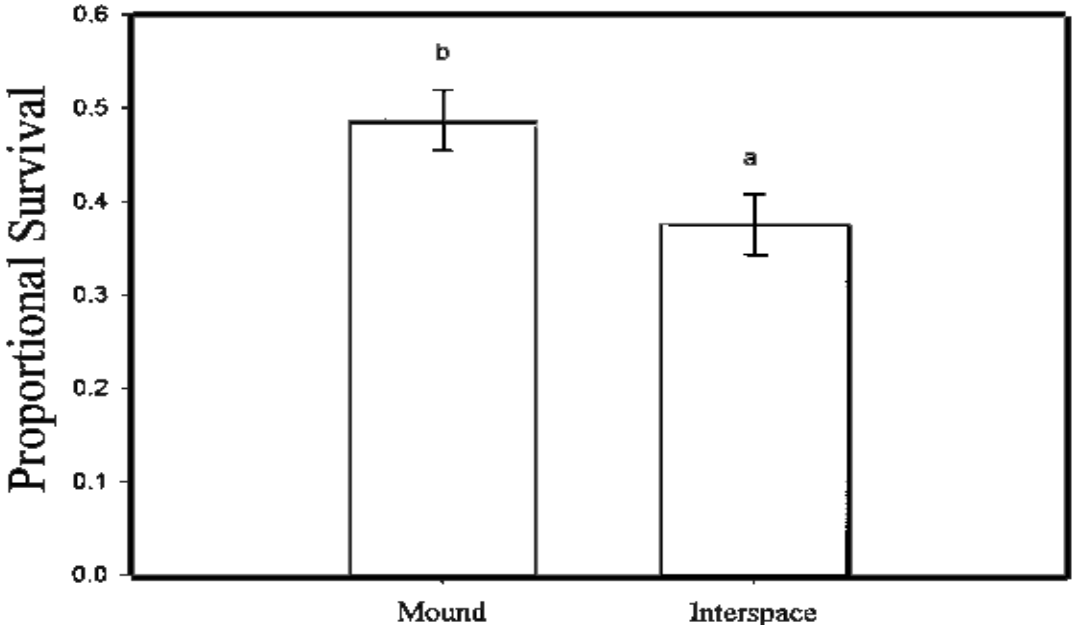

Figure 5. Mean proportional survival (+-S.E.) of combined emergent seedlings of *Crepis occidentalis* and *C. modocensis* in response to microsite. Different lower -case letters represent statistically significant differences at P<0.1.

purshii seedlings. Seedlings of *A. purshii* that emerged in the burned locations survived at twice the rate of those in unburned locations (P=0.06, Fig. 8). Survivorship for the first cohort of *A. purshii* did not differ among the treatments (Peto and Peto's logrank test, df=3, $\div^2$=4.3, P>0.25). There was some winter mortality among seeded *A. purshii* which was distributed evenly among treatments (Fig. 9). The low emergence for *A. purshii* resulted in low numbers of established plants with establishment higher in burned than unburned microsites.

Proportional survival of *Crepis* transplants differed between the factors within each main effect of species, burning and microsite, but no interactions occurred. Proportional survival of *Crepis* transplants was low for both species (< 14%), however survival of *C. occidentalis* was twice that of *C. modocensis* (P<0.01, Fig. 10). Regardless of species, survival of *Crepis* transplants was higher in burned treatments than unburned treatments (P=0.08, Fig. 11) and higher in mound than interspace microsites (P=0.02, Fig. 12).

Survivorship of the first cohort of *Crepis* transplants differed among treatments during different census periods (*C. modocensis* df=3, $\div^2$=9.8, P<0.025 and *C. occidentalis* df=3, $\div^2$ = 9.7, P<0.025). There was an initial rapid decline in survivorship (30 to 70%

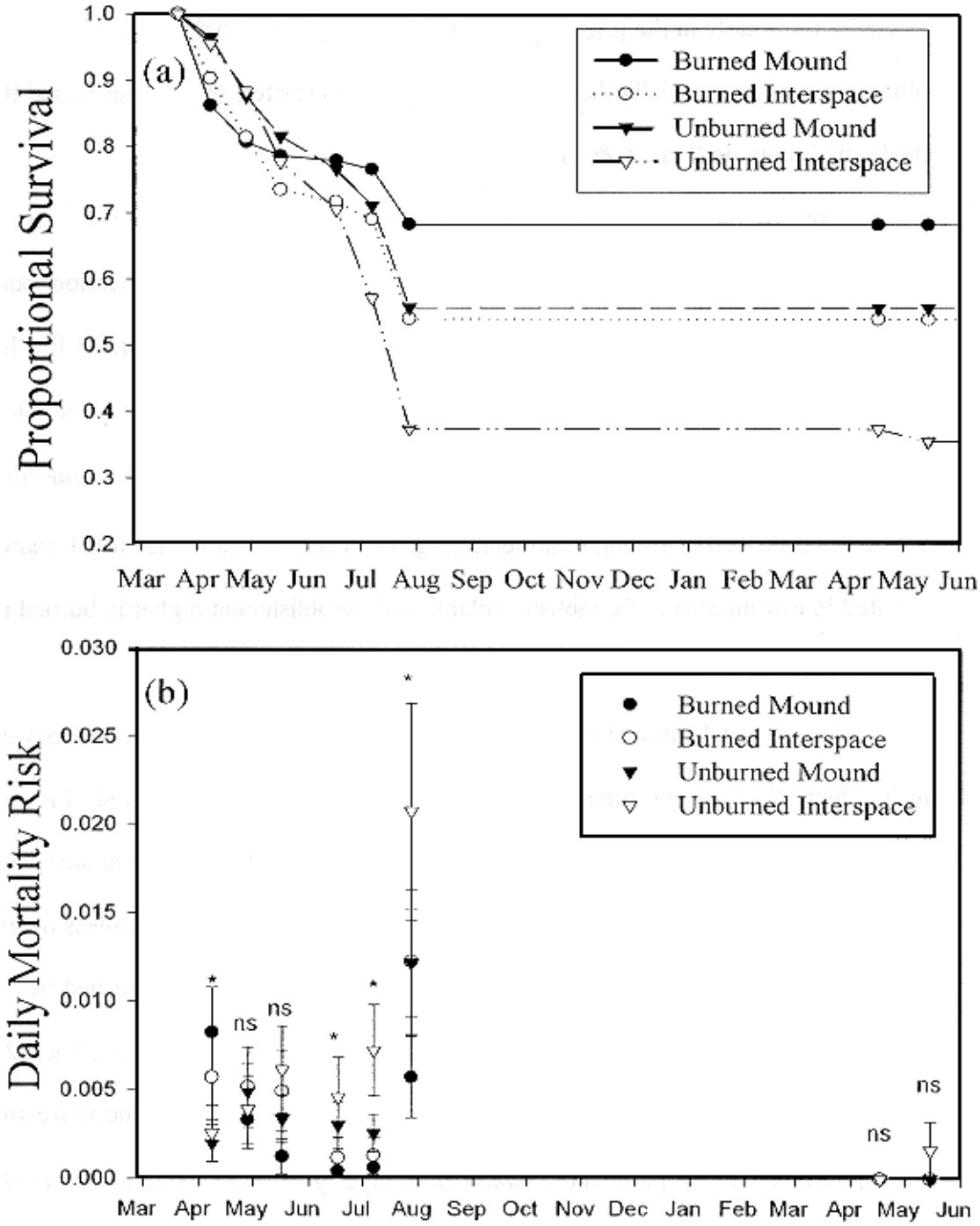

Figure 6. (a) Survivorship and (b) daily risk of mortality (95%C.I.)for seeded *C. modocensis* in four treatments during the 1998-1999 growing seasons. Daily mortality risks represent the average daily risk of dying for an individual plant in a partifular treatment for the preceding period. Asterisks above a set of daily mortality risks indicates that at least one treatment significantly differs from the others at that date. Sets with ns about them do not differ significantly.

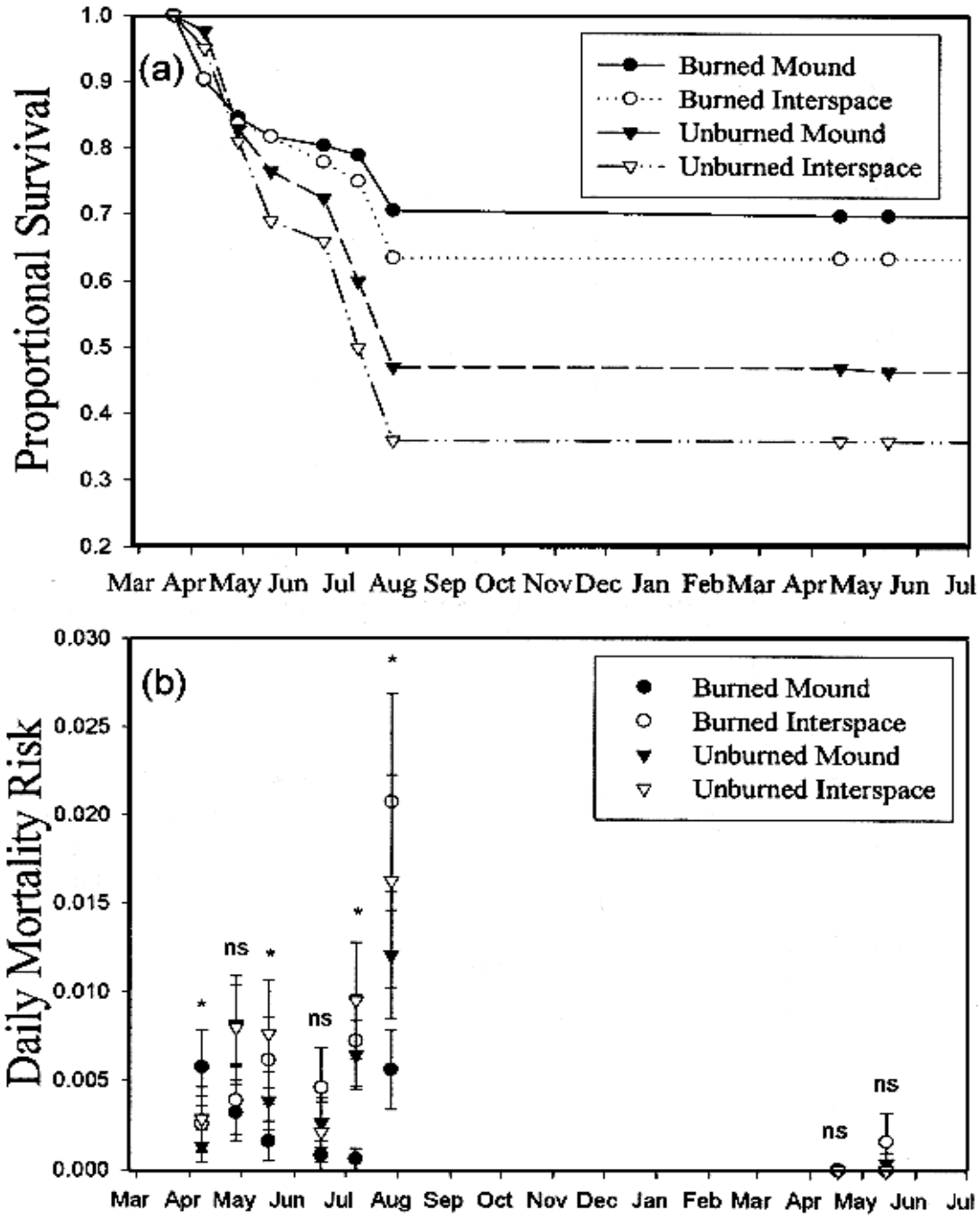

Figure 7. (a) Survivorship and (b) daily risk of mortality (95% C.I.) for seeeded *C. occidentalis* in four treatments during the 1998-1999 growing seasons. Daily mortality risks represnet the average daily risk of dying for an individual plant in a particular treatment for the preceding period. Asterisks above a set of daily mortality risks indicates that at least one treatment significantly differs from the others at that date. Sets with ns above them do not differ significantly.

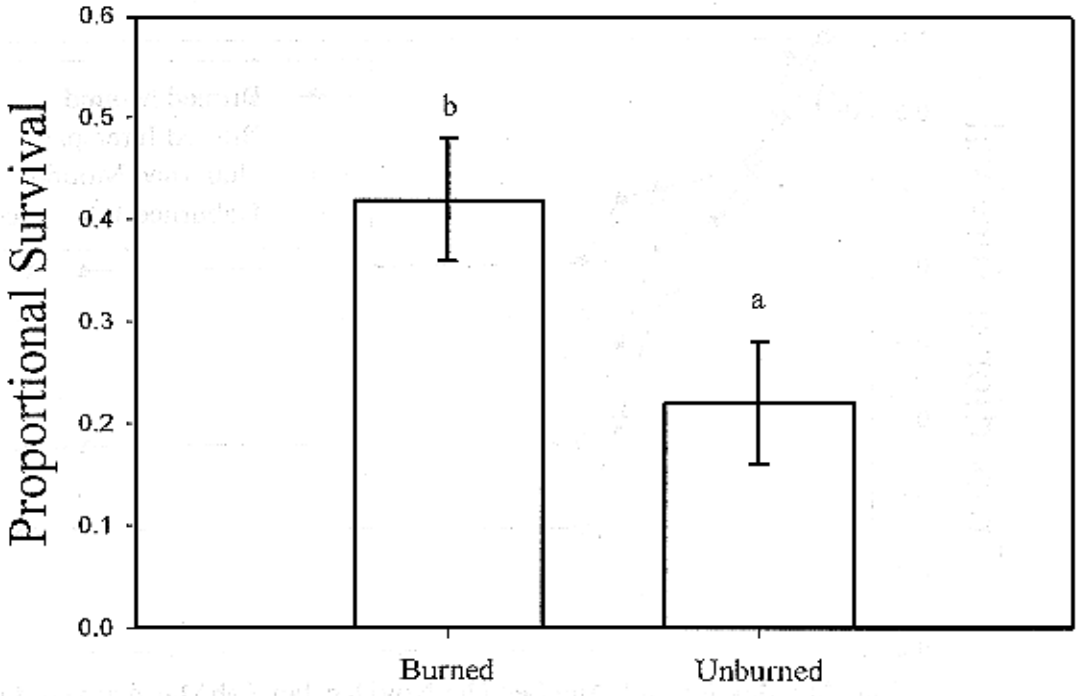

Figure 8. Mean proportional survival (± S.E.) of *A. purshii* seeds in response to fire. Different lower case letters represent statistically significant differences at $P<0.1$.

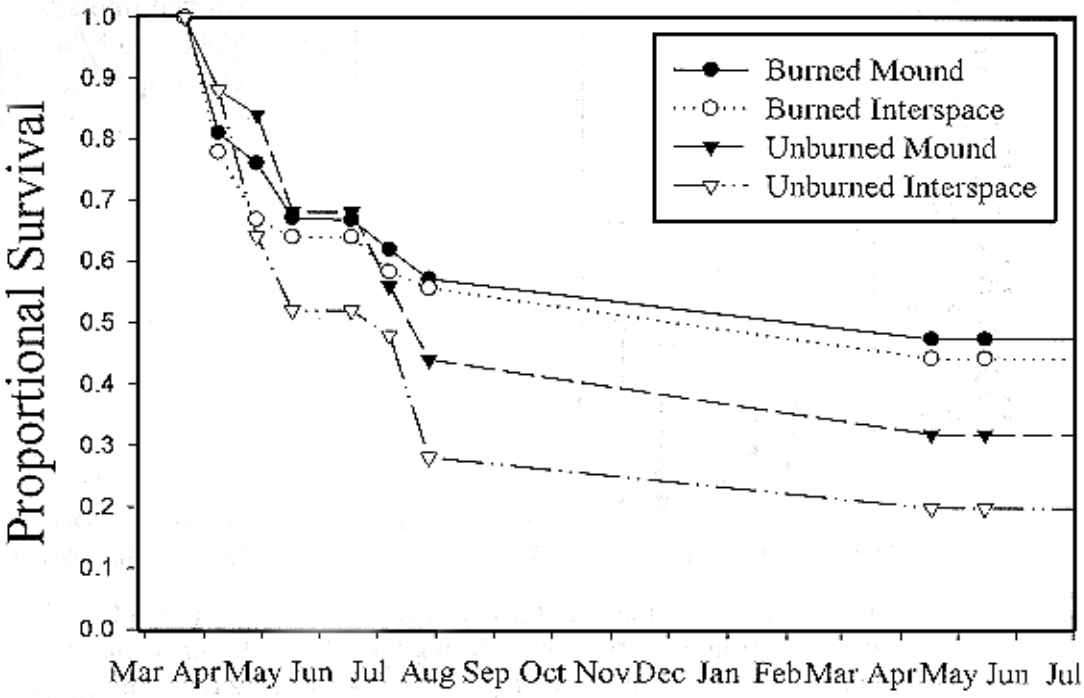

Figure 9. Survivorship of seeded *A. purshii* by treatment and census date during the 1998-1999 growing seasons.

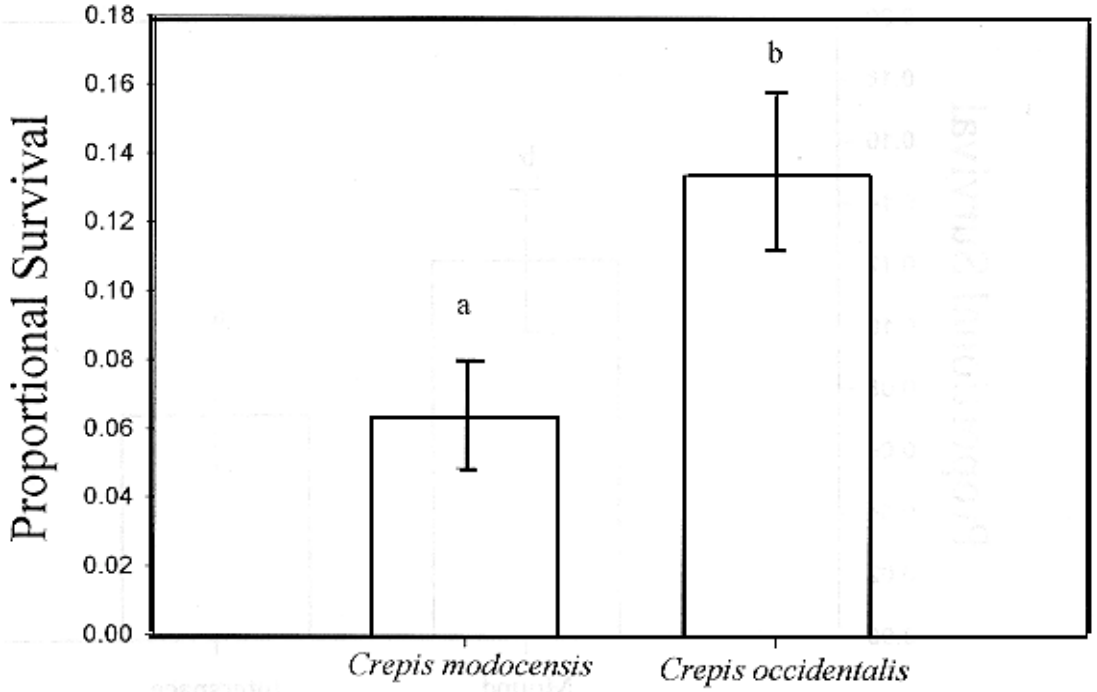

Figure 10. Mean proportional survival (± S.E.) of *Crepis* transplants by species. Different lower case letters represent statistically significant differences at P<0.05.

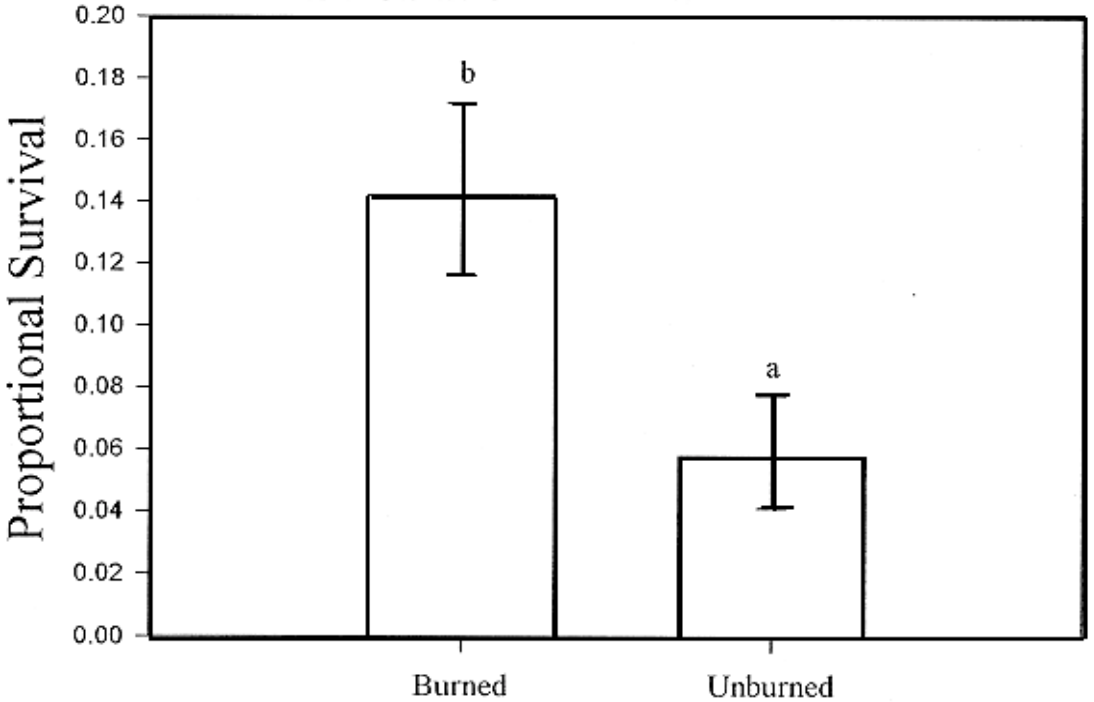

Figure 11. Mean proportional survival (± S.E.) of combined transplants of *Crepis* in response to fire. Different lower case letters represent statistically significant differences at P<0.1.

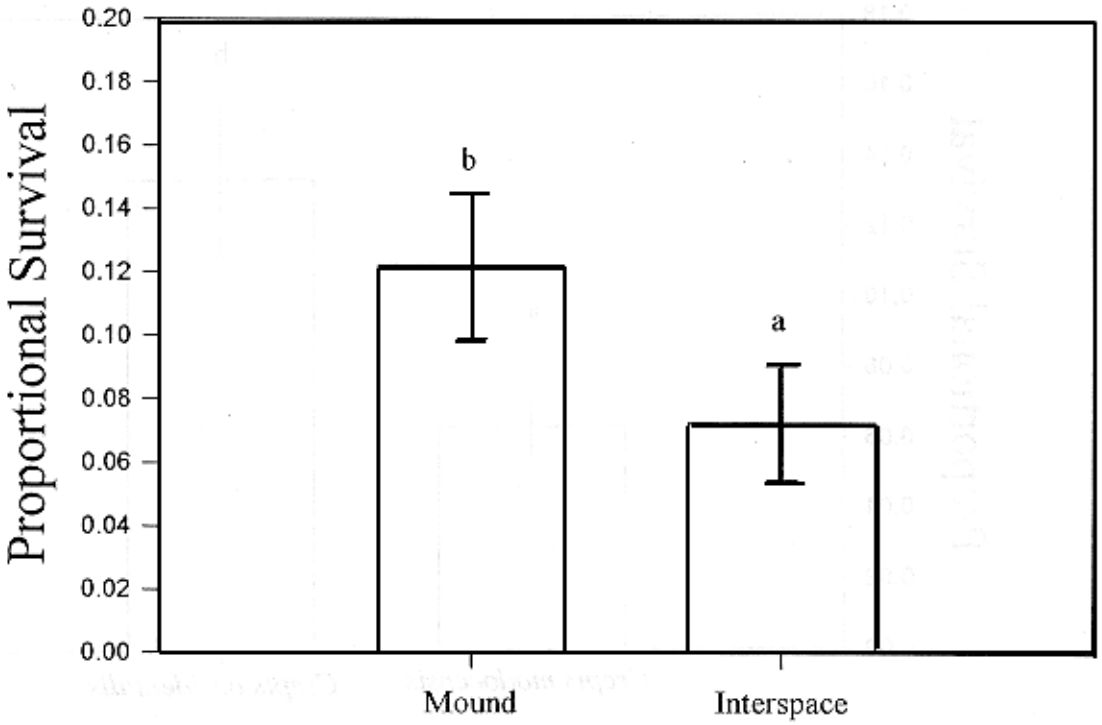

Figure 12. Mean proportional survival (± S.E.) of combined transplants of *Crepis* in response to microsite. Different lower case letters represent statistically significant differences at $P<0.05$.

mortality) during the first census after planting (Figs. 13a & 14a), but the only difference

among treatments for daily risk of mortality occurred during the 15 May through 15 June 1998 census date (Figs. 13b & 14b). In this period, the burned mound microsite for *C. modocensis* had significantly lower mortality and the unburned interspace for *C. occidentalis* had significantly higher mortality than the other three treatments. During all other census periods mortality risk did not differ significantly.

Transplants of *A. purshii* had similar proportional survival to those that emerged from seed. As with the seeded plants, transplants in burned treatments survived better than those in the unburned treatments (P=0.001, Fig. 15). Proportional survival did not differ significantly between microsites (P=0.53).

Survivorship of *A. purshii* transplants differed among treatments (df=3, $\div^2$= 57.9, P<0.01). Differential survival of *A. purshii* transplants in the burned vs. unburned treatments became apparent by the second census period and continued through most of the first year (Fig. 16). Daily mortality risk was significantly higher for at least one of the unburned treatments during all 1998 censuses.

Burning did enhance the likelihood of flowering of *A. purshii* transplants, 97 of the 99 transplants that flowered were in burned areas (24.6% vs. 0.5% flowered in the burned vs. unburned sites). Also, all of the 7 *Crepis* plants that flowered in this study were found in burned areas (6 in mounds, 1 in the interspace). Only the *A. purshii* transplants in burned areas reproduced enough for analysis. No significant difference in seed production

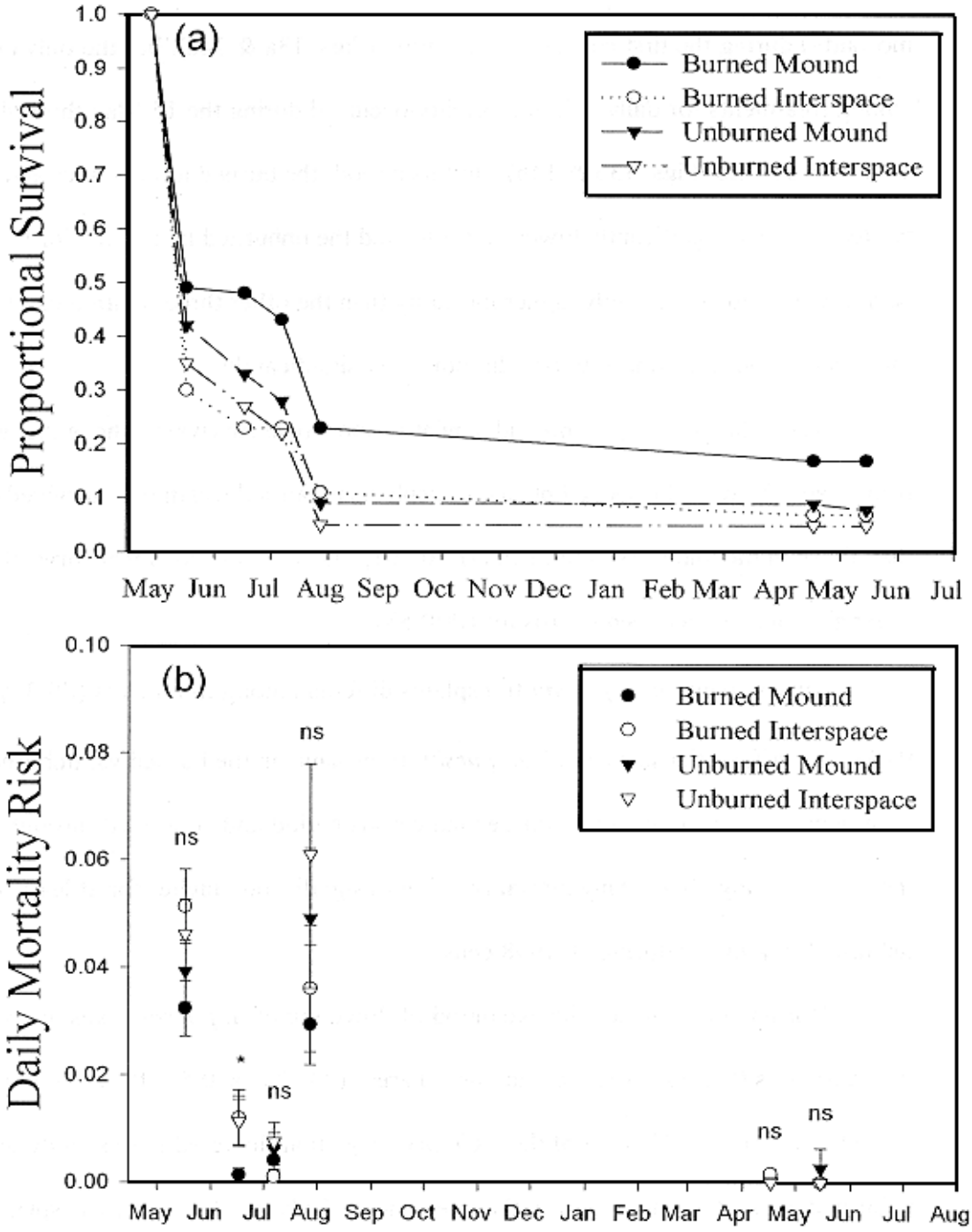

Figure 13. (a) Survivorship and (b) daily risk of mortality (95% C.I) for transplanted *C. modocensis* in four treatments during the 1998-1999 growing seasons. Daily mortality risks represent the average daily risk of dying for an individual plant in a particular treatment for the preceding period. Asterisks above a set of daily mortality risks indicates that at least one treatment significantly differs from the others at that date. Sets with ns above them do not differ significantly.

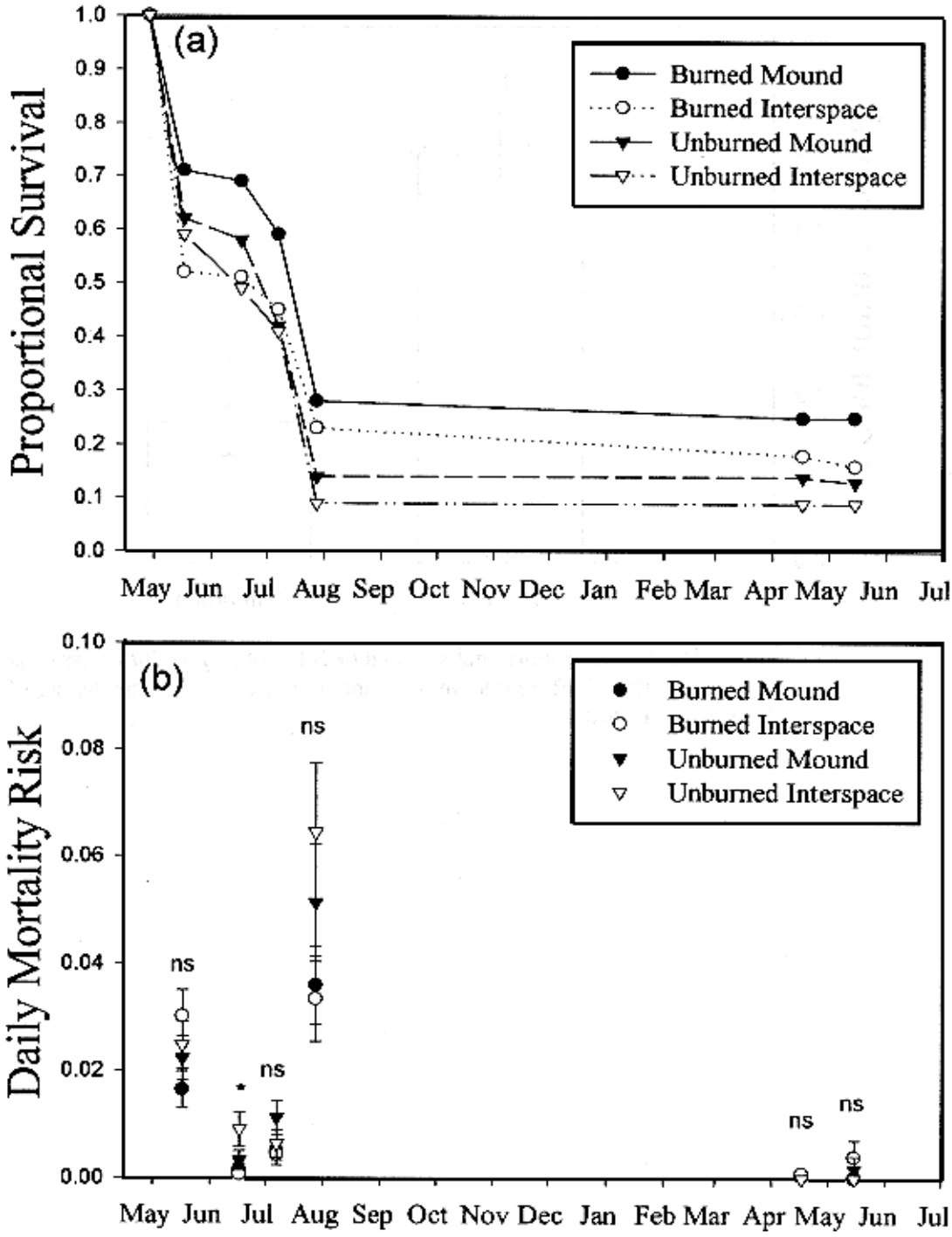

Figure 14. (a) Survivorship and (b) daily risk of mortality (95% C.I.) for transplanted *C. occidentalis* in four treatments during the 1998-1999 growing seasons. Daily mortality risks represent the average daily risk of dying for an individual plant in a particular treatment for the preceding period. Asterisks above a set of daily mortality risks indicates that at least one treatment significantly differs from the others at that date. Sets with ns above them do not differ significantly.

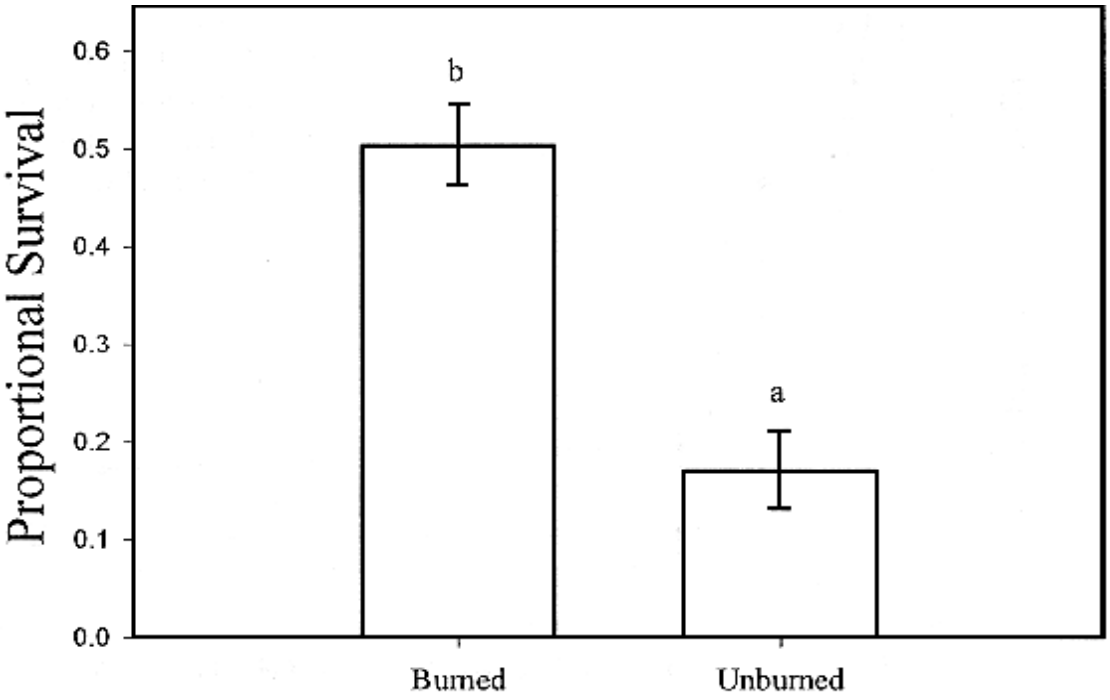

Figure 15. Mean proportional survival (± S.E.) of *A. purshii* transplants in response to fire. Different lower case letters represent statistically significant differences at $P<0.05$.

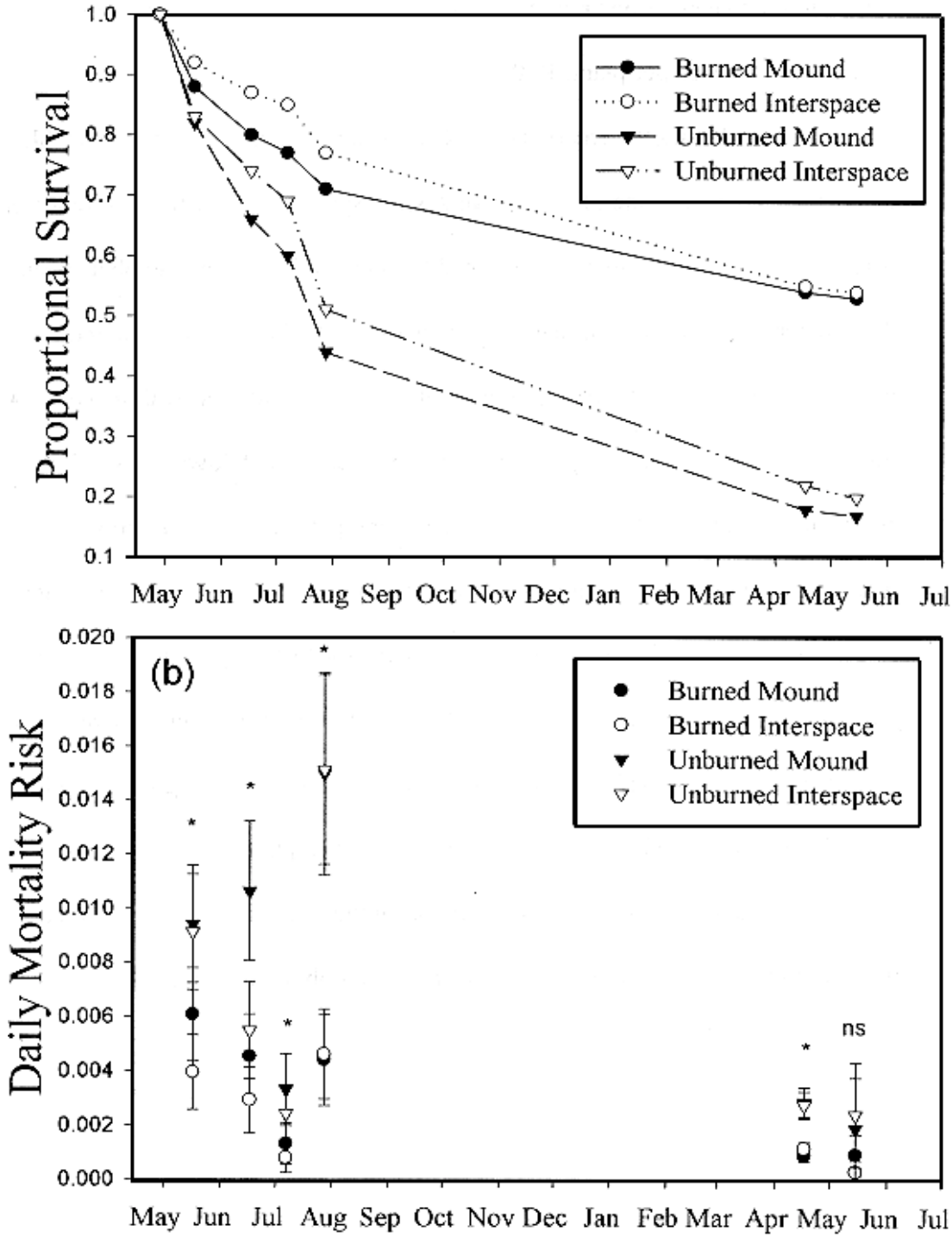

Figure 16. (a) Survivorship and (b) daily risk of mortality (95% C.I.) for transplanted *A. purshii* in four treatments during the 1998-1999 growing seasons. Daily mortality risks represent the average daily risk of dying for an individual plant in a particular treatment for the preceding period. Asterisks above a set of daily mortality risks indicates that at least one treatment significantly differs from the others at that date. Sets with ns above them do not differ significantly.

was found between burned mound microsites and burned interspace microsites (45.4 ± 7.9 vs. 29.6 ± 7.9 seeds per plant, P=0.25).

By combining the emergence and survival into a diagrammatic life table, comparisons can be made of seeding versus transplanting under the different treatments (Figs. 17-19). Transplants were assumed to begin with the same number of seedlings as those emerging from seed in these diagrams (instead of 150 for *Crepis* and 200 for *A. purshii*). These numbers were then multiplied by the actual survival of seeded and transplanted treatments. *Crepis* transplants showed a much lower survival and establishment than seedings, although the general pattern of higher survival in the burn treatments was similar to that of seeded plants. *C. modocensis* transplants yielded fewer established plants in all treatments than *C. occidentalis* transplants (Figs. 18 & 19). *A. purshii* had the highest survival and establishment of all transplants, however, when compared with the survival of an equal number of plants emerging from seeds, transplanting produced similar numbers of established plants (Fig. 19). At the end of the experiment, the overall survival of *A. purshii* in the two microsites was similar, however the burned treatments produced more plants than unburned treatments.

Crepis modocensis establishment

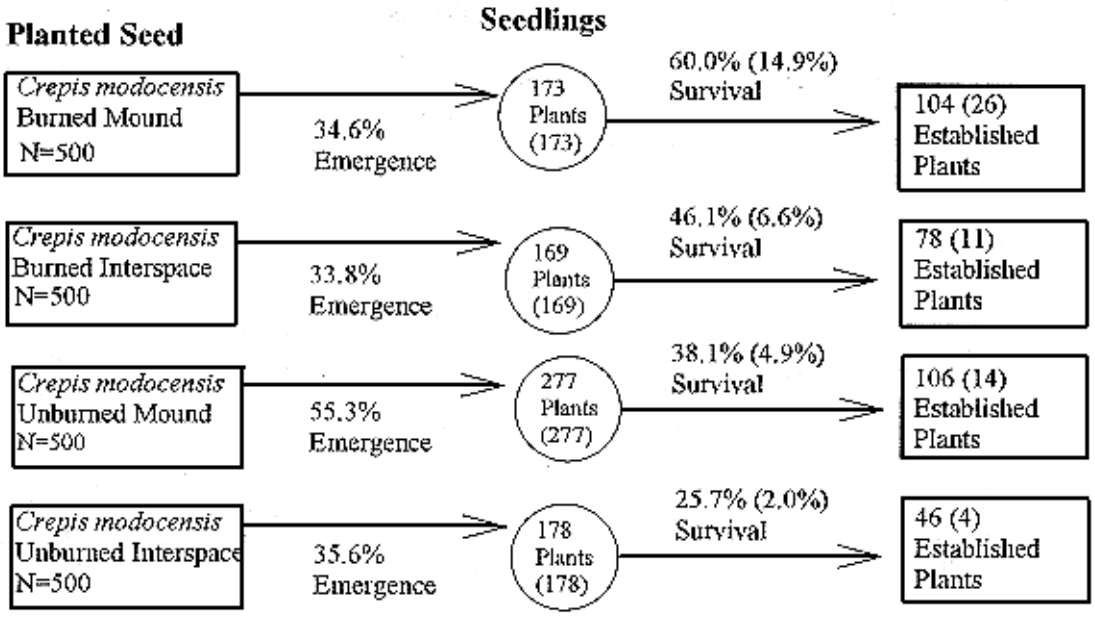

Figure 17. Diagrammatic life table of emergence, survival and establishment of *C. modocensis* plants. Figures in parentheses are begining number of transplants, transplant survival and established transplants of *C. modocensis*. To facilitate a direct comparison between seeds and transplants, beginning numbers of transplants were adjusted to match numbers of those emerging from seeds.

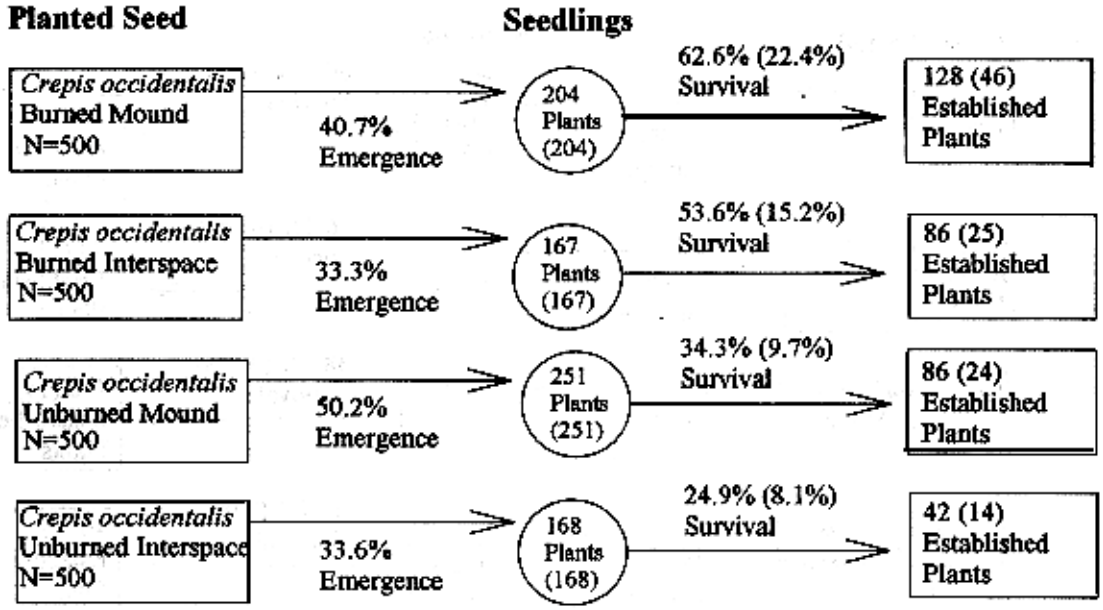

Figure 18. Diagrammatic life table of emergence, survival and establishment of *C. occidentalis* plants. Figures in parentheses are begining number of transplants, transplant survival and established transplants of *C. occidentalis*. To facilitate a direct comparison between seeds and transplants, beginning numbers of transplants were adjusted to match numbers of those emerging from seeds.

Astragalus purshii establishment

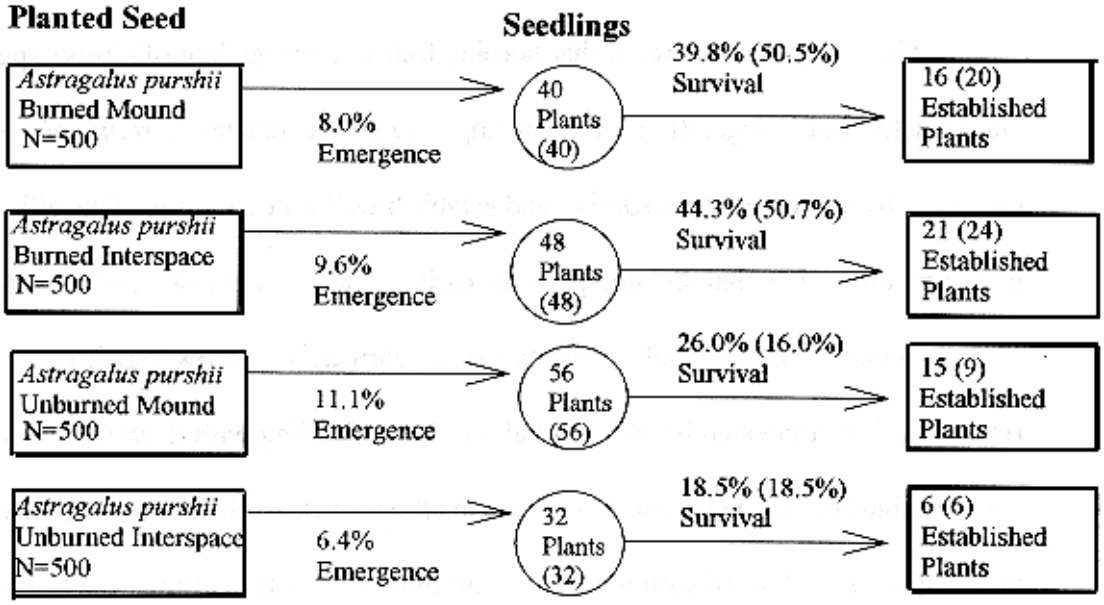

Figure 19. Diagrammatic life table of emergence, survival and establishment of *A. purshii*. Figures in parentheses are numbers for transplants. To facilitate a direct comparison between seed and transplants, beginning numbers of transplants were adjusted to match numbers of those emerging from seeds.

DISCUSSION

Plant Establishment

This study demonstrated that burning followed by seeding of *Crepis* species is a viable method of revegetation for enhancing sage grouse habitat. *Crepis* seedlings emerging from burned areas survive and establish well following fire. This effect is greater in mound microsites than in interspace microsites. Burned areas with greater proportions of mound microsites (i.e. higher densities of sagebrush) may show higher success when revegetated as suggested by Eckert et al. (1986b). Seeding with *A. purshii* resulted in low plant establishment due to low emergence in all treatments. Since seed viability was high in this species, and scarification enhanced germination for transplants, the low emergence is presumably because of physical dormancy derived from the hard legume seed coat. Seeds of *A. purshii* may continue germinating in successive years as seed coats are weakened and scarified, allowing imbibition to occur. However, the advantages to seedlings provided by prescribed fire such as reduced competition with sagebrush and increased nutrient availability decline with time following the fire (Young 1983, Bunting et al. 1988, Halvorson et al. 1997). We do not know if planting scarified seed of *A. purshii* would enhance spring germination, but this option warrants study. Transplanting of these species in this study resulted in few established plants and was considerably more laborious and costly than seeding.

Differences in soil surface microtopography are known to be important as safe sites in the emergence of plants (Harper et al. 1977, Eckert et al. 1986a, 1986b). Although microsite and burning did influence emergence of *Crepis* and *A. purshii*, no single treatment favored emergence of all species. For *Crepis*, emergence was highest in unburned mounds. There are several reasons why higher

emergence might be expected in mounds as opposed to interspaces. Germination in the soil depends on several conditions including soil-seed contact, depth of planting, temperature, light, moisture availability and dormancy (Booth and Haferkamp 1995) . Soil in mound microsites has a soft consistency and fine structure whereas interspace areas often form hard surfaces called vesicular crusts which have low water infiltration often leading to pooling and movement of soil due to freezing and thawing of soil water (Eckert et al. 1986a, Hugie and Passey 1964). The fine soil structure within mounds increases the chance of good soil-seed contact while the lack of a physical soil crust lowers the chance that the seedling will be physically hampered from breaking through the soil surface. Higher levels of organic carbon in the soil and litter of mounds capture and hold water more efficiently than interspace areas. Inhibitory characteristics of interspace microsites include the presence of vesicular crusts, low organic matter content in soil and lack of a litter layer. Moisture stress of seedlings in interspaces is more common due to lack of litter, runoff of moisture, increased irradiation and evaporation. Interspaces often exhibit higher water potentials in the first 5 cm of soil than mounds (Chambers 2000).

Crepis emergence in the unburned mounds might be higher than burned mounds due to two factors. Moisture capture in the form of snow is increased around intact sagebrush canopies (Allen 1988), thus unburned mounds gain relatively more moisture during the important winter period for soil moisture recharge than burned mounds. Also, lower *Crepis* emergence in burned mounds may be due to wind erosion following the fire (personal observation). This erosion might reduce the seed pool in burned areas by physically moving seeds to unfavorable microsites.

Contrary to my expectations, the emergence of *A. purshii* was highest in burned interspaces despite potentially unfavorable microsite conditions. *A. purshii* often occurs naturally in interspace areas next to rocks (personal observation), the harsh interspace soils may be more susceptible to frost heaving than litter covered mounds, providing *A. purshii* seed with more abrasion, a mechanism for scarification, and allowing germination to begin.

While emergence sets the upper limit of established plants for a treatment, it was not indicative of future establishment in this study. Greater emergence of *Crepis* in unburned mounds was accompanied by greater mortality, resulting in lower overall establishment. Burning significantly increased the survival of both seeded and transplanted plants of all three species. Although not significant during every census period, there was generally greater risk of mortality for plants in the unburned microsites compared to the burned microsites in 1998, with the exception of the first census date. Therefore, increased plant establishment in burned treatments was primarily due to increased survivorship rather than differential emergence.

Higher survival in burned areas is likely a result of three factors, decreased competition due to removal of sagebrush, release of nutrients following fire and early phenology. Competition with adult sagebrush has been shown to be effective at reducing seedling establishment (Reichenberger and Pyke, 1990). Therefore, removal of sagebrush would be expected to increase the chance of seedling establishment compared to an intact stand. Secondly, fire increases the amount nitrogen, phosphorus, potassium, calcium, magnesium and sodium that was previously bound in living and dead materials (Wright and Bailey 1982). This nutrient flush is available to plants emerging from seed or vegetative organs the following spring,

providing an enhanced nutrient environment for growth and establishment. The third factor for increased establishment in burned areas is earlier seedling emergence due to increased temperatures caused by higher interception of sunlight and greater albedo of the black soil surface in the vicinity of the mounds. Lack of vegetation in burned areas and unburned interspace areas result in more extreme fluctuations of temperature on the soil surface (Daubenmire 1968), possibly stimulating germination earlier than in the unburned mound areas. Earlier emergence in burned treatments would cause a higher chance of observing mortality during the first census date in these treatments compared to unburned treatments. In this situation, the growing season for plants in burned areas would be longer, possibly aiding establishment. During 1999, mortality was low among all species and treatments, supporting the conclusion that these plants had established. These three factors allowed seedlings of *Crepis* and *A. purshii* in burned areas to attain a size where establishment was likely.

For *Crepis*, overall survival was higher in the mounds than in interspaces, although within the burned and unburned areas there was no statistical difference between microsites. Higher survival in mound microsites is most likely a combination of those factors that resulted in higher emergence in unburned mounds and those factors that led to higher survival in the burned mounds.

Although there was little reproduction among the plants in this study, it is obvious that burning does increase the chance of reproduction for *A. purshii*. Burning may also reduce the age-to-first-reproduction for these forbs, which should aid in population fitness and contribute to increases in population sizes over time.

Management Implications

Results from this study suggest that burning has a beneficial effect on the establishment of these three forbs. The effect of microsite on survival is smaller, but could be important for large scale revegetation efforts.

Prescribed fire is effective at reducing sagebrush density, but forb response after fire is dependent on the pre-burn community. Forbs that are present in the pre-burn community respond well after fires because they are released from competition with sagebrush and are able to capture and use available nutrients (Wright 1985). Still, prescribed burning has not been shown conclusively to increase forbs important to sage grouse (Fischer 1996), but some evidence points to this possibility (Pyle & Crawford 1996, Wrobleski 1999). As Humphrey (1984) notes, succession is not always predictable, but is dependent on pre-disturbance site conditions and the vital attributes of the pre-disturbance species present on a particular site (Drury and Nisbet 1973, Noble and Slatyer 1980). Three groups of vital attributes described by Noble and Slatyer (1980) are 1) method of persistence and arrival during and after a disturbance, 2) length of time to reach certain life stages and 3) the ability to establish and grow in the post-disturbance community. The vital attributes of each species interact to define the composition of the post-disturbance community.

There are many areas where forbs and more palatable perennial grasses have been depleted and less preferred grasses, exotic annuals, and sagebrush remain in the community (Miller et al. 1994). The vital attribute of dispersal is important for forbs after disturbance in these conditions. A species can be considered present on a site if it occurs in vegetative form or as seeds in the soil. The determination of whether a species is present and at what levels is simple if the foliage is visible,

however, determining whether a species is present in the seed bank is more difficult. Plants that have long-lived seed may not be present in the current community, but may occur in the seedbank (such as *A. purshii*). Plants with short-lived seed (such as *Crepis*) that are not present in the community probably do not have a local seedbank and must arrive either through emigration or revegetation. Questions that need to be asked include: are there populations of forbs on site or close enough for dispersal to the site to occur? If so, what are the mechanisms of dispersal? Wind dispersal (such as *Crepis*) may allow forbs from adjacent areas to colonize burns, but even wind dispersal is limited in its effective distance (Silvertown 1993). Plants dispersed by insects or without special dispersal mechanisms will require long periods of time to reach the site. If forbs are depleted and dispersal to the site is not likely to occur, seeding forbs may be required.

Seeding of forbs with a seed drill will create a higher risk of mortality to existing perennial grasses. Drilling seeds of both grasses and forbs may be necessary to maintain the desired grass-forb mixture. However, drilling presents technical problems due to the different seed sizes and planting depth requirements. Broadcast seeding and harrowing may be a less invasive and effective method of adding forb seed to depleted sites that already maintain a perennial grass cover.

Prescribed burning alone will have optimal benefits for improving sage grouse habitat when both grass and forb components are still present in the plant community. The results of this study indicate that increased establishment of *C. modocensis*, *C. occidentalis* and *A. purshii* following fire will occur when seeds of these plants are naturally in the seed bank. Burning after the forb/grass component is reduced and sagebrush density is high will decrease the chance of a favorable response to burning due to the absence of available propagules and reduction in the

magnitude of resource islands surrounding sagebrush plants in dense stands. Under these conditions revegetation may be necessary.

It is unclear how much time sage grouse will spend foraging in burned patches when interspersed with stands of sagebrush. However, establishment of perennial forbs in these areas will provide future sage grouse forage as sagebrush re-invades and reaches an acceptable density for sage grouse cover requirements. Using fire to increase forage for sage grouse should be an option for land managers where appropriate, but revegetation of native forbs may also be necessary and can be effective. Currently, the major obstacles to using forbs like *Crepis* in restoration efforts is the commercial availability of the seed. Seed would need to be collected and increased by a seed producer to obtain adequate quantities. Production of native seed by growers is typically more expensive than grasses due to variable demand, crop failure and startup costs. Also, forb seeds are typically more difficult to produce due to weed invasion and limited weed control methods (Bermant and Spackeen 1997). The time and effort required for seed gathering, cleaning, germination and planting are different for each species and establishment method. *A. purshii* seed must be collected by hand due to the low stature of the plant whereas *Crepis* is taller and some mechanical collection may be possible. If transplanting is used there are the additional costs of scarification, proper storage/stratification, greenhouse care and finally field transplantation. In general, transplantation will be more expensive and require more labor than seeding operations. For transplants to be economically beneficial, the increased transplant cost (germination, greenhouse care, and planting) must be less than the costs associated with seeding (seed cleaning and planting) when differential success rates are taken into account. This means that transplants would have to show much higher establishment success than

seeds to be an economically viable method of restoration. Based on this criteria, transplanting these three species is not an economically viable alternative.

Seeding of *A. purshii* could be effective if a method to increase emergence were developed or if it was found that non-scarified seed was long-lived in the soil and kept germinating over a number of years. Seeding of *Crepis* species has good potential because of its high viability, ease of germination, high seed production and wide distribution. Increasing interest is emerging in using native seeds on rangelands in the western US to maintain genetic and ecological diversity (Richards et al. 1998). *Crepis* species have the potential to be produced at the commercial level and made available to land managers to use in seeding projects.

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