Wildfire Rehabilitation Success With and Without Chaining on the Henry Mountains, Utah

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Abstract—We sampled unchained and chained areas in 2004 and 2005 on the Henry Mountains that had been aerially seeded after the Bulldog Fire of 2003. Establishment of seeded grasses was high on unchained and chained areas although chaining increased seeded grass establishment on some sites. Western yarrow established well on unchained areas. Initially, high seedling emergence in 2004, followed by high precipitation in late winter 2005, produced 15 to 25 percent total seeded plant cover on both unchained and chained areas by summer of 2005. Aerial seeding at lower elevations and with less precipitation usually requires some form of seed coverage to be successful.

Introduction

Wildfire is a natural disturbance in the Western United States that has been actively suppressed and also reduced by removal of fine fuels by grazing of domestic livestock (Blackburn and Tueller 1970; Burkhardt and Tisdale 1976; Gruell 1986; Horman and Anderson 1999; Miller and Wigand 1994; Naillon and others 1999; Young and Evans 1981). Fire suppression increased the spread and density of pinyon pine (*Pinus edulis* and *P. monophylla*) and Utah juniper (*Juniperus osteosperma*). Under more frequent fire return intervals, pinyon and juniper trees were mainly found in dense stands on areas of dissected topography or had a savanna-like distribution (Burkhardt and Tisdale 1969; Miller and Rose 1994; Miller and Tausch 2001; Miller and Wigand 1994). These trees are now encroaching into big sagebrush (*Artemisia tridentata*) communities on alluvial fans (Naillon and others 1999).

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As pinyon and juniper density increases in an area, biomass of understory perennial vegetation is greatly reduced (Arnold and others 1964; Barney and Frischnecht 1974; Clary 1971; Dye and others 1995; Miller and others 1995; Tausch and Tueller 1990; Tress and Klopatek 1987; Vaitkus and Eddleman 1991; Wilson and Schmidt 1990); the native seed bank is also r educed (Koniak and Everett 1982; MacDonald 1999; Poulsen and others 1999; West and Van Pelt 1987). Along with a reduction of perennial understory biomass, there is also a change in the species composition from perennials to annuals, with cheatgrass (*Bromus tectorum*) as a prominent species (Armentrout and Pieper 1988; Bunting and others 1999; Everett and Koniak 1981; Poulsen and others 1999; Schott and Pieper 1985).

Dense pinyon-juniper forests eventually burn (Goodrich and Rooks 1999), leaving little native understory to reestablish on the site. Crown fires, in these dense stands, occur under very hot and dry conditions (Bunting and others 1999; Erskine and Goodrich 1999; Gruell 1999; Swetnam 1988), and kill rhizomes, roots, and seeds of other species (Zwolinski 1988). If cheatgrass is present, it will use soil water and nutrient resources made available by the fire and dominate the disturbed site (Evans and Young 1978; Harris 1967; Hironaka 1994; Nasri and Doescher 1995a,b; Pyke and Novak 1994; Young and Evans 1978). Thus, after fire in a dense pinyon-juniper stand, recovery of native understory is slow and the area is often "dominated by introduced annuals" (Erskine and Goodrich 1999). The lack of sufficient perennial understory to recover after fire indicates that a biotic threshold has been crossed (Tausch 1999a, b; Whisenant 1999). Restoration of such areas may require substantial investment in weed control and revegetation.

To prevent weed dominance, soil erosion, and costly restoration, burned areas are rehabilitated by seeding as soon as possible after fire, using funds from the Emergency Fire Rehabilitation (EFR) program of the Federal Government. The goal of the EFR program is to prevent soil erosion and weed establishment after a fire (Utah BLM 2001). Burned areas are preferably seeded with a rangeland drill to best control distribution, rate, and depth of seeds. But drills cannot be used on steep slopes, rocky soils, or those with obstacles such as tree skeletons (MacDonald 1999). Burned forests are usually aerially seeded. An anchor chain may be dragged one-way over the ground after seeding (Thompson and others 2006) to help cover the seed and increase the number of seeds in "safe sites" (Harper and others 1965; Young 1988). Chaining has been shown to increase establishment of seeded species and reduce weed dominance after aerial seeding burned areas between 1,615 and 1,810 m elevation (MacDonald 1999; Ott and others 2003).

Burned areas of the Henry Mountains were seeded after the Bulldog fire burned more than 12,000 ha in the summer of 2003. The BLM administers more than 11,000 ha of the burned area with 7,700 ha designated as Wilderness Study Area (WSA). Only native species are permitted to be seeded and no mechanical treatments are allowed on WSA sites. The Utah Division of Wildlife Resources (UDWR) also administers sections of the burned area owned by the State of Utah. Since much of the burned area had moderate to steep slopes and was rugged, it was aerially seeded. Some sites were chained, while steep slopes, archaeological sites, and the WSA were left unchained. Chaining costs may vary and equipment transport costs were high for this remote site. Chaining for this project cost $141/ha. The cost of chaining and difficulty in its implementation led to the question of whether it was really necessary to chain after aerial seeding at relatively higher elevation (>1,900 m) burned sites such as those on the Henry Mountains. The objective of this study was to compare seeded species establishment on unchained and chained sites on the Henry Mountains and generally evaluate the success of the Bulldog fire rehabilitation on seeded areas above 1,900 m elevation.

Study Sites and Methods

The Henry Mountains are located in the southeast quarter of Utah. The Bulldog fire burned between the elevations of 1,800 and 3,400 m (Leroy Mead, Personal communication, Utah Division of Wildlife Resources, Price, Utah). Ignited by a four-wheeler, the fire burned from the second week of July and was not considered out until the end of August 2003 (Brant Hallows, personal communication, Richfield Field Office, Bureau of Land Management). Plant communities before the fire were mostly pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*), with understory shrubs that included Wyoming big sagebrush (*Artemisia tridentata* var. *wyomingensis*), mountain big sagebrush (*Artemisia tridentata* var. *vaseyana*), or black sagebrush (*Artemisia nova*), or mixed conifer woodlands with little understory and cheatgrass present on some sites. The burned area has moderate to steep slopes, with sandy loam dioritic and sedimentary soils that are locally highly erosive.

Burned areas were aerially seeded using fixed-wing aircraft in November and December 2003. Seeding included four different seed mixes (table 1). The WSA mix consisted of only native species while the other three mixes had both native and introduced species. Designated seeded areas were chained from the end of March to the end of April 2004. Normally, chaining after fall seeding is completed by December. An ely chain was pulled by two D8 and D9 bulldozers 30 m apart and in a J or U shape. An ely chain is an anchor chain with railroad segments welded perpendicular to some of the links to provide additional weight and disturbance of the soil (Vallentine 1989). Different sites were seeded with different seed mixes depending on whether they were on UDWR or BLM land, and whether or not they were in the WSA. The Aspen, Benson A, and Coyote sites were seeded with the same seed mix on both unchained and chained areas, but those mixes were different for each site. The Benson B and Cass Creek sites were seeded with the same mix at each site, but those mixes were different for unchained and chained areas. The Aspen Creek site was seeded with the UDWR low elevation mix on both unchained and chained areas. The Coyote Creek site was seeded with the UDWR high elevation mix on both unchained and chained areas. The Benson A site was seeded with the BLM non-WSA mix on both unchained and chained areas. The Benson B and Cass Creek sites were seeded with the BLM-WSA mix on unchained areas in the Wilderness Study area and with the BLM non-WSA mix on the chained area.

Vegetation Sampling

In the spring of 2004 five paired study sites were chosen for intensive sampling. Four of these sites were intensively sampled August 2004 and 2005. One of the sites was omitted after the first year because of inability to distinguish between chained and unchained areas. Intensively sampled study sites were located on the southern half of the mountains between 2,100 and 2,700 m elevation (table 2). Study sites included adjacent unchained and chained transects with similar aspect, slope, and elevation.

Intensive Sampling—On each site, two or three permanently marked 120–150 m transects were laid out contiguously. Perpendicular to each transect, five 30-m cross-belts were centered at random distances from the end. On each cross-belt, 20 0.25 m^2 quadrats were placed every 1.5 m. In each quadrat, canopy cover and density were recorded. Canopy cover was estimated using a modified Daubenmire (1959) cover class method (Bailey and Poulton 1968) with seven cover classes: (1) 0.01 to 1 percent, (2) 1.1 to 5 percent, (3) 5.1 to 25 percent, (4) 25.1 to 50 percent, (5) 50.1 to 75 percent, (6) 75.1 to 95 percent, (7) 95.1 to 100 percent. Cover was calculated by averaging the midpoints of each cover class across all quadrats for a site. Cover was recorded for vegetation (total and individual species), litter, rock, pavement, cryptograms, and bare ground. Density was only recorded for perennial species.

Shrub cover was measured using the line intercept method on all the cross-belts (Bonham 1989). Shrub density was measured with belt transects centered over the length of each cross-belt. Each shrub belt transect was 30 m in length and 1.34 m wide, for a total of 0.004 ha. Burned tree density was also measured on the unchained sites at points spaced 30 m apart along the baseline using a point-quarter method. At each point, the distances to the center of the nearest tree skeleton base was measured for each quarter of the area centered on the point. A BLM rain gage at Coyote Bench provided precipitation data (data on file Henry Mountains BLM office, Hanksville, Utah).

Extensive Sampling—Seven additional WSA-unchained and non-WSA chained paired sites, as well as 14 non-paired WSA-unchained sites were extensively sampled. The paired WSA-unchained transects, seeded with the WSA mix, were compared to chained transects seeded with the BLM non-WSA mix. Density of seeded shrubs, grasses, and forbs, as well as that of residual perennial plants and annual plants, were recorded in 40 0.25 m^2 quadrats placed 1.5 m apart along a 60-m transect in each treatment. Forb and shrub data were collected by species, but seeded perennial grass species were counted in total and not by species.

Table 1—Bulk seeding rates (kg/ha) for species seeded after the 2003 Bulldog fire on the Henry Mountains, Utah. **(**UDWR = Utah Division of Wildlife Resources; high = high elevation mix; low = low elevation mix; BLM = Bureau of Land Management; WSA = Wilderness Study Area mix; non = non-WSA mix; N = species native to the United States; I = species introduced to the United States.)

Seeded species	Accession	Scientific name	UDWR N or I	UDWR high	BLM low	BLM non	WSA
Grasses							
Sandberg bluegrass	MH	*Poa secunda*	N				1.1
Mountain brome	Bromar	*Bromus marginatus*	N	1.1			3.5
Arizona fescue	Redondo	*Festuca arizonica*	N		0.6		
Hard fescue		*Festuca brevipila*	I	0.9			
Sheep fescue		*Festuca ovina*	I	0.7			
Prairie junegrass		*Koeleria macrantha*	N		0.2		
Spike muhly	El Vado	*Muhlenbergia wrightii*	N	0.07			
Orchardgrass	Paiute	*Dactylis glomerata*	N	0.9	0.6		
Indian ricegrass	Rimrock	*Achnatherum hymenoides*	N			0.5	
Crested wheatgrass	Hycrest	*Agropyron cristatum* x *Agropyron desertorum*	I	0.6	1.1	2.8	
Intermediate wheatgrass		*Thinopyrum intermedium*	I		1.1		
Pubescent wheatgrass		*Thinopyrum intermedium*	I		1.1		
Pubescent wheatgrass	Luna	*Thinopyrum intermedium*	I			2.7	
Slender wheatgrass	Pryor	*Elymus trachycaulus*	N	1.1			
Slender wheatgrass	SanLuis	*Elymus trachycaulus*	N				3.8
Tall wheatgrass	Alkar	*Thinopyrum ponticum*	I			2.1	
Thickspike wheatgrass	Critana	*Elymus lanceolatus*	N		1.1		2.1
Blue wildrye	Arlington	*Elymus glaucus*	N	1.1			
Russian wildrye	Bozoisky	*Psathyrostachys juncea*	I		1.1	2.7	
Forbs							
Alfalfa	Ladak	*Medicago sativa*	I		1	0.5	
Alfalfa	Ranger	*Medicago sativa*	I	1.1	0.1		
Arrowleaf Balsamroot		*Balsamorhiza sagittata*	N	0.03			
Rocky Mountain Beeplant		*Cleome serrulata*	N	0.1	0.6		
Small Burnet	Delar	*Sanguisorba minor*	I	0.8	1.3		
Small Burnet	VNS	*Sanguisorba minor*	I	1.4			
Blue Flax	Appar	*Linum perenne* spp. *lewisii*	I	0.2	0.3	0.2	0.2
Cicer Milkvetch	Windsor	*Astragalus cicer*	I	0.7			
Sainfoin		*Onobrychis viciifolia*	I		1.2		
Bird's-foot Trefoil		*Lotus corniculatus*	I	0.6			
Western Yarrow		*Achillea millefolium*	N	0.02			0.2
Shrubs							
Bitterbrush		*Purshia tridentata*	N	a	a		
Mountain Big Sagebrush		*Artemisia tridentata* var. *vaseyana*	N	0.6	0.3		
Wyoming Big Sagebrush		*Artemisia tridentata* var. *wyomingensis*	N		0.6		
Fourwing Saltbush		*Atriplex canescens*	N	a	a	0.5	
Utah Serviceberry		*Amelanchier utahensis*	N	a	a		
Total rate excluding dribbler mix			12.1	12.3	12.4	10.8	

[a] included in dribbler mix and seeded at 1.1 kg/ha over part of the area.

Table 2—Locations of intensively-sampled fire rehabilitation sites, associated soil series and classifications (Downs 1990) on the Henry Mountains, Utah.

Sites	NAD 27 UTM coordinates Northing	Easting	Soil series	Classification
Aspen Creek	4198420	525550	Circleville-Blazon complex	Aridic Argiborolls Ustic Torriorthents
Benson	4199230	527690	Montosa	Aridic Argiustolls
Cass Creek	4194930	523980	Duneland-Mido complex	Ustic Torripsamments
Coyote Creek	4202750	521860	Duneland-Mido complex	Ustic Torripsamments

Cover of rock, litter, and bare ground was occularly estimated in cover classes in these quadrats in 2004 and 2005. Cover of seeded grasses, shrubs, and forbs, along with that of annual and residual perennial plants, was also occularly estimated in cover classes in 2005. Extensive sampling was done in late June 2004 and 2005.

Analysis

Second year seeding success was categorized for all intensively and extensively sampled WSA-unchained, unchained, and chained transects according to plant density: <0.5 seeded plants/m^2 = failure, 0.5 to 2 seeded plants/m^2 = moderately successful, and >2 seeded plants/m^2 = successful. Density means for 0.25 m^2 quadrats were converted to plants/m^2 by multiplying by 4.

Because most sites were seeded with different seed mixes, initial analysis for both the intensively sampled and extensively sampled data used different sampling sites as random blocks and compared categories of seeded species: total seeded grasses, total seeded forbs, and the sum of seeded grasses and forbs as herbaceous vegetation. For the intensively sampled data, two initial analyses were conducted in this manner: (1) using the Aspen, Benson A, and Coyote sites as blocks, and (2) a separate analysis using the Benson B and Cass Creek sites as blocks. To better sort out responses to chaining, analysis of sites and treatments was subsequently conducted for categorical vegetation responses using transects as pseudoreplicates for the intensively sampled data, and quadrats as pseudoreplicates for the extensively sampled data (Hurlbert 1984). This allowed us to determine site by treatment interactions. Reasonable inference using pseudoreplication is dependent on having similar site characteristics on both treated and untreated areas. Our sampled areas were selected to be similar in site characteristics. Finally, density and cover of dominant seeded species were analyzed for unchained and chained areas for each site separately, using transects as pseudoreplicates for the intensively sampled data and quadrats as replicates for the extensively sampled data. Mixed model analysis (Littell and others 1996) was used for analysis of all extensively and intensively sampled data. Sites or transects were considered random for the intensively sampled data and sites or quadrats were considered random for the extensively sampled data. Data for the 2004 and 2005 sampling years were analyzed separately, and intensively and extensively sampled data were analyzed separately. All individual quadrats were considered subsamples for treatment analysis, except when considered as pseudoreplications for the extensively sampled data.

Although seed mix was confounded with chaining treatment or among different sites or blocks, comparisons are useful because land management agencies will continue to seed different mixes on different sites. Native seed mixes will be sown on wilderness study areas that cannot be chained, while native and introduced species will be sown on non-wilderness study areas that can be chained.

Results and Discussion

The relationship of increasing pinyon-juniper density and cover, and correspondingly decreasing understory species density and cover varies with soil depth and climate (Miller and Tausch 2001). A post-fire stand reconnaissance showed that the burned pinyon and juniper communities on the Henry Mountains generally had limited residual understory plants with a relatively high tree density of 912 trees/ha. Median rock cover for the intensively sampled sites was 23.6 percent. From January 2004 to August 2004, 74 mm of precipitation helped seeded plants to establish and reach an average of 6.5 percent cover by August 2004 on the intensively sampled sites. Between September 2004 and August 2005, the sites received 662 mm of precipitation, which supported high plant survival and significantly increased cover the second year after seeding (fig. 1). Overall, plant establishment from the fire rehabilitation seeding was highly successful.

WSA General Success

The two WSA sites that were intensively sampled (Benson B and Cass Creek) had >2 seeded plants/m^2 on every transect the second year after seeding and were therefore considered to be successfully seeded. Total seeded species cover was over 25 percent on the intensively sampled sites (fig. 2).

Of the 21 extensively sampled WSA transects, 19 had >2 seeded plants/m^2 by the second year and were considered successfully seeded. These transects averaged about 30 percent cover of all seeded species (fig. 3). Because the two failed transects were on similar soils and at similar

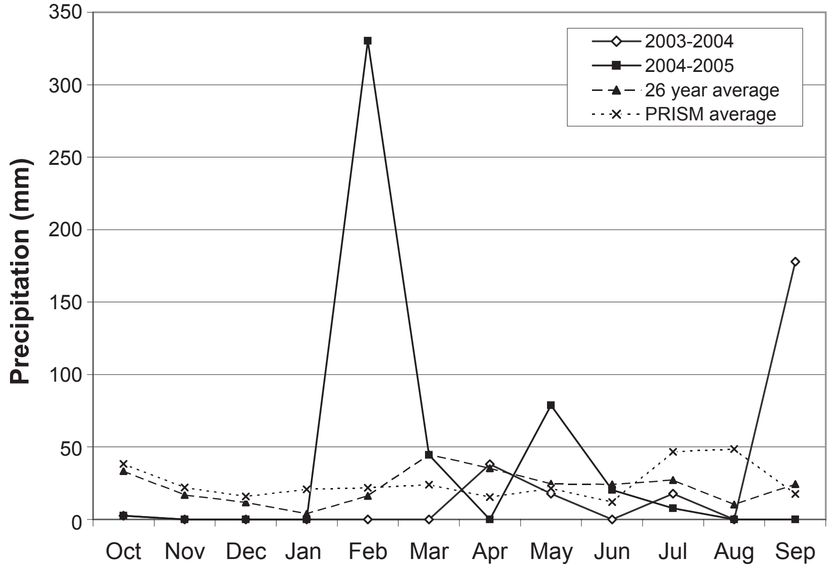

Figure 1—Monthly precipitation at BLM weather station at Coyote Bench (data on file at Henry Mountains BLM office, Hanksville, Utah) and estimated from PRISM (Parameter-Elevation Regression on Independent Slopes Model available at http://forest.moscowfsl.wsu.edu/engr/climatesw.html) for the Aspen Creek sampling site, Henry Mountains, Utah. Annual amounts in mm were 254 for 2003–2004, 484 for 2004–2005, 273 for the 26-year average, and 304 for the PRISM average.

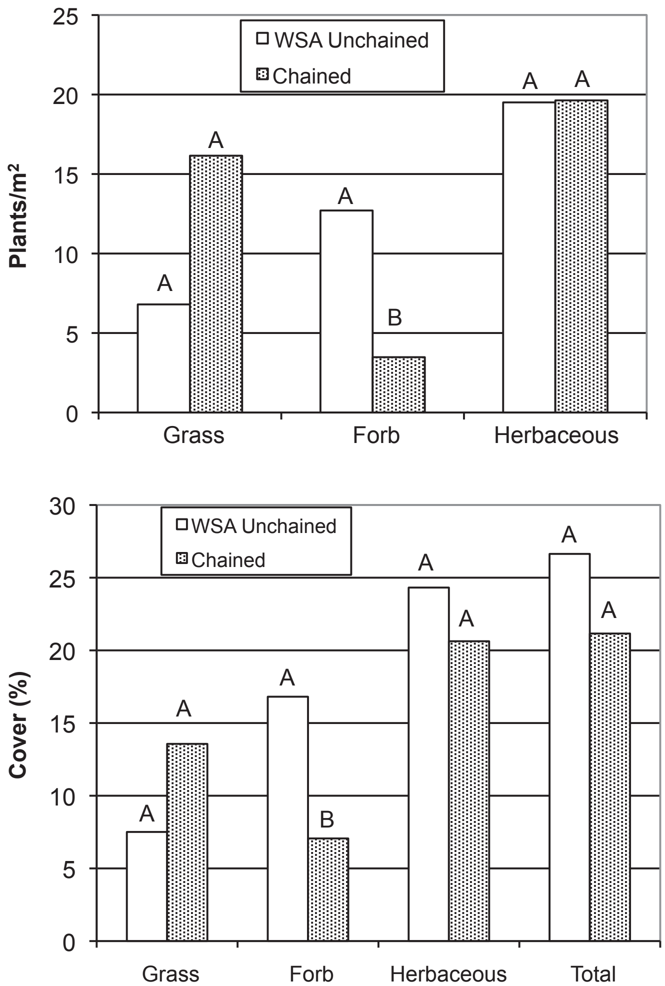

Figure 2—Density and cover of seeded species on intensively sampled WSA unchained and chained fire rehabilitation sites in the Henry Mountains, Utah in 2005. Total is all herbaceous seeded vegetation plus the shrubs on the sites. Different letters for pairs of bars indicate a significant difference ($p < 0.05$).

elevations as the successful transects (fig. 4), we conclude that these transects were either missed or on the margin of the aerial seeding operation. Davis and Harper (1990), Goodrich and Rooks (1999), and Thompson and others (2006) observed a reduction of weedy species with successful establishment of seeded species, and increased weed cover with seeding failure. We did not observe high densities or cover of cheatgrass on failed (evidently unseeded) extensively sampled sites, but found Coyote tobacco (*Nicotiana attenuata*) and pinyon groundsmoke (*Gayophytum ramossisimum*) to be dominant plants there. Native winter annuals are easily replaced within a short time by cheatgrass. Bare ground and available resources on some of these sites could result in cheatgrass invasion and dominance in the future.

Density of seeded species was much higher in 2004, the first year after seeding, than in 2005 (fig. 5). Seedings always decrease in density as established plants mature and use more resources per plant. Density of seeded grasses in 2005 was significantly ($p > 0.01$) correlated with 2004 density ($r^2 = 0.41$), which emphasizes the importance of initial seedling establishment.

Unchained Versus Chained Transects: Extensively Sampled Sites

Chained treatments had significantly ($p < 0.05$) greater grass density and cover than unchained treatments in both 2004 and 2005 (fig. 6). Unchained treatments had significantly higher seeded forb cover ($p < 0.05$) and density ($p < 0.0561$) than chained treatments in 2005. For the pseudoreplication analysis of 2005, data, site, chaining treatment, and the site by chaining treatment interaction was significant ($p < 0.001$) for seeded grass cover and density and seeded forb cover and density. Seeded grass cover percentages were greater on chained than unchained treatments on three sites (Stanton Pass = 20.5 ± 1.7 chained, 7.8 ± 1.7 unchained; Dark Canyon = 21.6 ± 1.7 chained, 6.4 ± 1.7 unchained; and Cass Creek = 10.5 ± 1.7 chained, 1.1 ± 1.7 unchained).

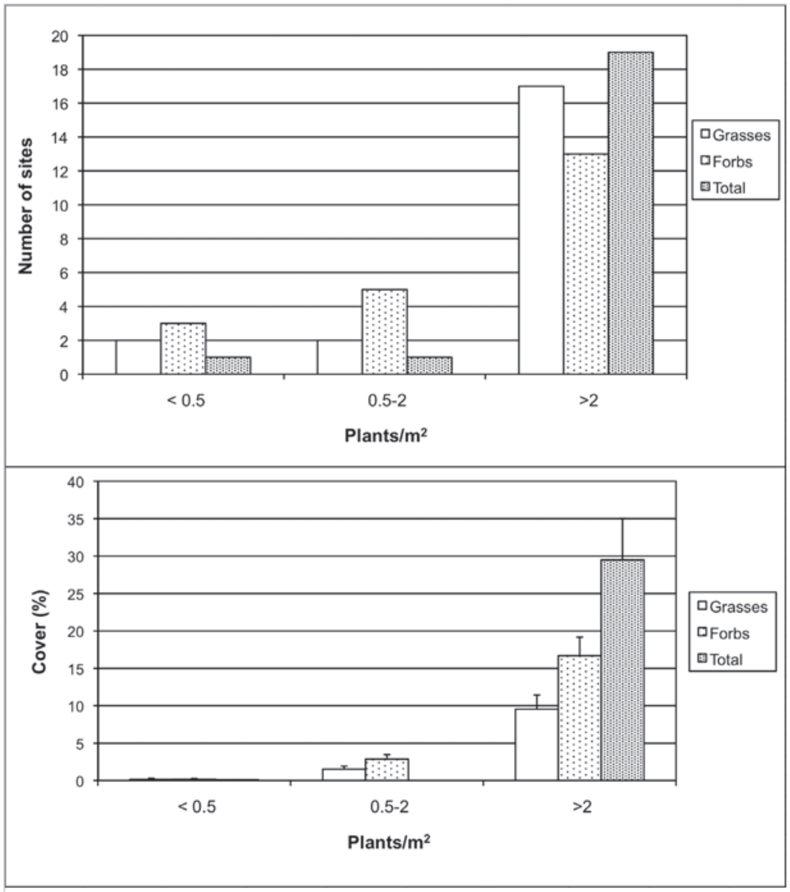

Figure 3—Number of sites out of 21 that had different densities of seeded grasses, forbs, and total plants (above) and percent cover (below) associated with those density categories for unchained Wilderness Study Area fire rehabilitation sites in the Henry Mountains, Utah, in 2005.

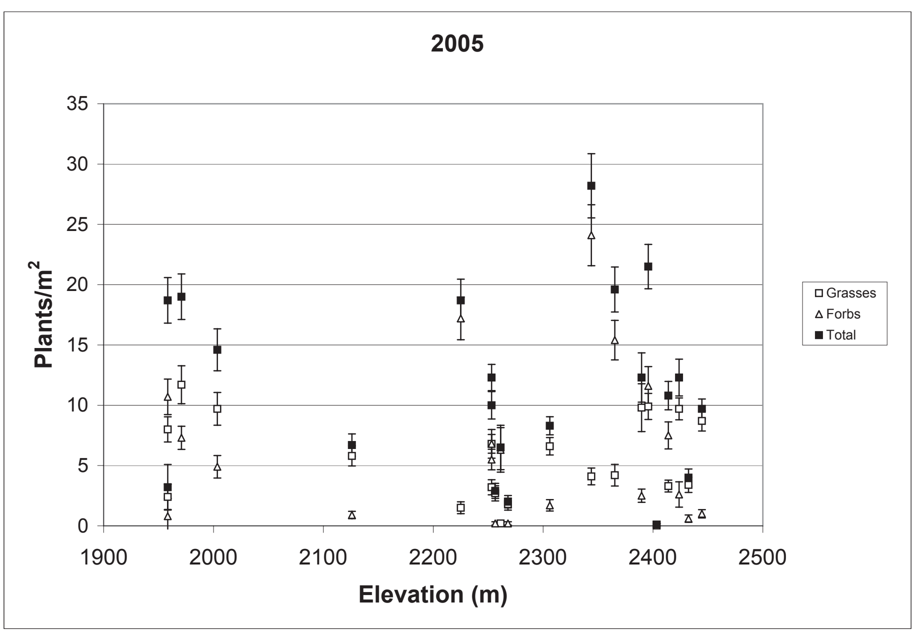

Figure 4—Density of seeded species on 21 extensively sampled fire rehabilitation sites in the Henry Mountains, Utah, in relation to site elevation. Each point represents 2004 and 2005 density data at a site.

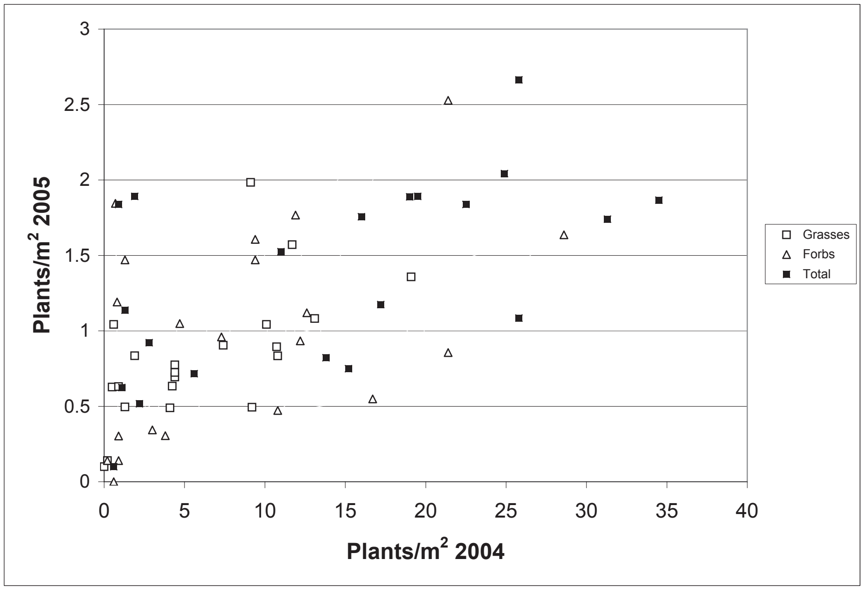

Figure 5—Density in 2004 and 2005 on 21 extensively sampled fire rehabilitation sites in the Henry Mountains, Utah.

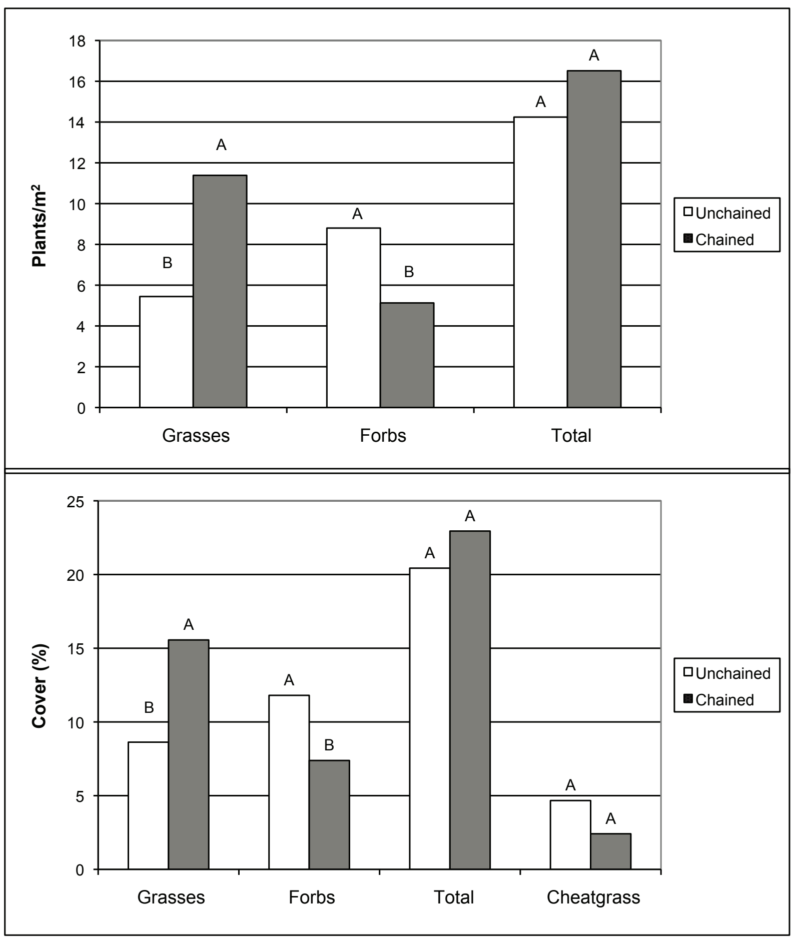

Figure 6—Density and cover of seeded grasses and forbs in 2005 on seven extensively sampled unchained and chained paired sites in the Henry Mountains, Utah. Paired bars with different letters are significantly different ($p < 0.05$ for all but forb density where $p < 0.0561$).

Seeded grass density (plants/m^2) was greater on chained than unchained treatments at four sites (Aspen Creek = 11.6 ± 1.0 chained, 6.0 ± 1.0 unchained; Dark Canyon = 14.8 ± 1.0 chained, 3.6 ± 1.0 unchained; Corral Canyon = 15.6 ± 1.0 chained, 10.0 ± 1.0 unchained; and Cass Creek = 10.8 ± 1.0 chained, 1.6 ± 1.0 unchained) of the seven site-pairs. Because the chained areas were seeded with introduced and native grasses (BLM non-WSA mix), and the unchained areas were seeded with only native grasses (BLM WSA mix), it is not possible to determine whether greater density and cover of seeded grasses on chained than unchained treatments for the extensively sampled sites was a result of chaining, better establishment of introduced species than native species, or both.

Seeded forb cover and density were also significant ($p < 0.001$) for site, chaining treatment, and the interaction of site and chaining treatment for the pseudoreplication analysis. Seeded forb cover percentages were greater on unchained than chained treatments for two of the seven sites sampled (Stanton Pass = 2.1 ± 1.9 chained, 11.9 ± 1.9 unchained; Cass Creek = 15.4 ± 1.9 chained, 27.1 ± 1.9 unchained). Seeded forb density (plants/ m^2) was greater for unchained than chained treatments on three of the seven site-pairs sampled (Corral Canyon = 4.0 ± 1.2 chained, 11.6 ± 1.2 unchained; Cass Creek = 9.2 ± 1.2 chained, 17.2 ± 1.2 unchained; and Bulldog Peak = 16.8 ± 1.2 chained, 24.0 ± 1.2 unchained). All extensively sampled unchained treatments were WSA sites. Western yarrow (*Achillea millefolium*) was only seeded on the WSA unchained areas (BLM-WSA mix, seeded at 0.2 kg/ha) and was not designated to be seeded on the unchained areas that were extensively sampled (BLM non-WSA mix). It was the dominant forb encountered in sampling both unchained and chained areas and averaged 10.4 percent cover across all WSA-unchained sites. The range of yarrow relative cover on unchained sites was 0–96 percent with a mean of 45 percent. Yarrow cover on chained sites was 6.8 percent. The range of yarrow relative cover on chained sites was 0–100 percent with a mean of 39 percent. Western yarrow on many chained extensively sampled sites must have drifted onto these sites from aerial seeding on the adjacent WSA. Higher densities and cover of western yarrow on unchained than chained extensively sampled sites may be because chaining reduced yarrow establishment; but is much more likely because the unchained area had many more seeds than did the chained area where seeds landed by drift or misapplication.

Where chained areas on some sites had greater density and cover of seeded grasses than on unchained sites, seeded forb cover and density (mainly yarrow) was greater on some unchained than chained sites. Even with differences in cover and density of seeded grasses and forbs among sites, most of the extensively sampled sites were considered successful with the establishment of >2 seeded plants/m^2. Seeded plant density was not correlated with elevation (fig. 4).

Unchained Versus Chained Transects: Intensively Sampled Sites

Sites as Blocks—Total seeded plant cover and density for both 2004 and 2005 were similar between unchained and chained treatments when analyzing the Aspen, Benson A, and Coyote sites containing the same seed mix on each treatment of the site, but different seed mixes between sites (table 3). Seeded perennial plant density in 2005 was >2 plants/m^2 on almost every belt of these transects. Most belts averaged ≥9 perennial plants/m^2. An exception was one belt that averaged two perennial plants/m^2 on the Aspen Creek site. Other belts on the unchained treatment at that site also had lower densities of perennial plants than the rest of the belts on the site. We conclude that parts of this site were either missed or marginally seeded. There was also a higher density of annual weeds on these belts. Average cheatgrass cover on the Aspen site was 1.9 ± 0.3 percent on the unchained transects and 5.2 ± 0.4 percent on the chained

Table 3—Significance of sites and chaining treatments on density and cover of seeded perennial grasses and forbs in 2005 after the Bulldog fire on the Henry Mountains, Utah.

Sites sampled and analysis	Effects	Density			Cover		
		Grass	Forb	Total	Grass	Forb	Total
Sites as blocks							
Aspen, Benson A, Coyote	Chaining	NS	NS	NS	NS	NS	NS
Cass Creek, Benson B	Chaining	NS	0.04	NS	NS	NS	NS
Transects as psuedoreplicates							
Aspen, Benson A, Coyote	Site	NS	NS	NS	NS	NS	NS
	Chaining	NS	NS	NS	NS	NS	NS
	Site×chaining	0.01	0.01	0.01	NS	0.01	0.01
Cass Creek, Benson B	Site	NS	NS	NS	0.05	NS	NS
	Chaining	0.05	0.05	NS	NS	0.05	NS
	Site×chaining	0.05	NS	0.05	0.01	NS	0.01

transects, suggesting that more of the chained than unchained area was missed during the seeding. Second year data on these sites showed no significant differences (p > 0.05) in density and cover between unchained and chained treatments when native and introduced species where analyzed separately (fig. 7).

Analysis of the Benson B and Cass Creek sites, which were seeded with different mixes on each treatment but the same seed mixes between sites, showed that seeded forb cover and density were higher on WSA-unchained than chained treatments in 2005 (fig. 2). The higher forb density on the WSA transects is a result of high establishment of western yarrow (table 4), which was not designated to be seeded on the chained areas at these two sites.

Overall, established species included a high proportion of seeded species on each site whether unchained, chained, all native seed mix, or a native and introduced seed mix (table 5). All sites included perennial species that were not in the seed mix to be seeded on that specific site, but evidently received seeds from another mix seeded in an adjacent area, due to seeding overlap, drift, or both.

Site by Treatment Interactions—For the Aspen, Benson A, and Coyote sites, there was a significant site by chaining treatment interaction for all variables tested, except for seeded perennial grass cover (table 3). Perennial grass cover was similar on unchained and chained treatments for all sites, but perennial grass density was higher on chained than unchained treatments at the Benson A site (fig. 8). Crested wheatgrass (*Agropyron cristatum* or *desertorum*) had higher cover on chained than unchained areas at the Benson A site, but the reverse was true at the Aspen site (table 4). Higher density of crested wheatgrass on the unchained Aspen site may have been due to a small residual population of crested wheatgrass observed in early spring 2004 at this site. Chaining may have reduced the residual crested wheatgrass density at the Aspen site. Very few residual perennial grasses were observed in early spring 2004 after the fire on most areas of this study.

Perennial forb cover and density were similar for unchained and chained treatments at the Aspen site (fig. 8). The unchained treatment had higher cover and density than the chained treatment at the Benson A site, but the reverse

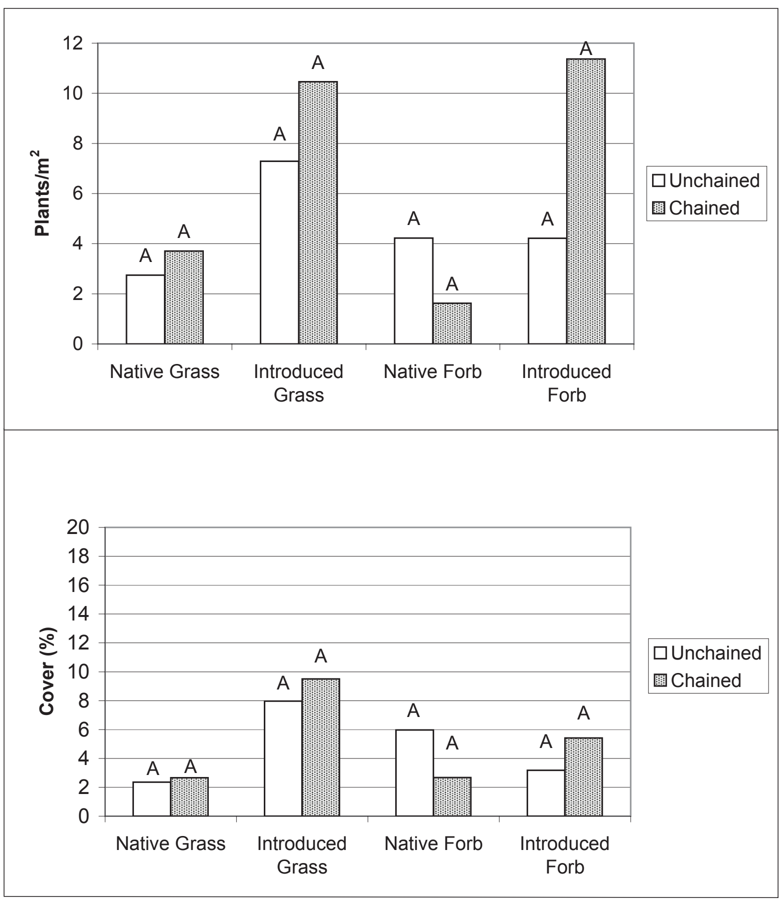

Figure 7—Effects of chaining on density and cover in 2005 of native and introduced species seeded for fire rehabilitation on Aspen, Benson A, and Coyote sites on the Henry Mountains, Utah. Native forb data includes blue flax as a naturalized forb. Different letters above pairs of bars indicates a significant difference (p < 0.05).

Table 4—Cover and density in 2005 of dominant and other selected species seeded on unchained and chained sites on the Henry Mountains, Utah. UC = unchained, C = chained.

Species	Aspen- UDWR low elevation mix				Benson A- BLM non-WSA mix				Coyote- UDWR high elevation mix			
	UC	C	UC	C	UC	C	UC	C	UC	C	UC	C
	Cover (%)		Density (plants/m^2)		Cover (%) (plants/m^2)		Density (plants/m^2)		Cover (%)		Density	
Grasses												
Mountain brome	0[b]	0.9[b]	0[b]	0.4[b]	0[b]	0[b]	0[b]	0[b]	0.4	1.4	0.2	2.1
Slender wheatgrass	1.0	0.6	1.0	0.6	2.7[a]	0	2.1[a]	0	0.3	2.4	0.9	4.9
Crested wheatgrass	7.2[a]	3.2	6.4	3.2	2.7	4.3	3.1	7.4	5.7	2.6	5.9	2.3
Intermediate wheatgrass	2.4	4.3	2.4	3.6	1.6	1.9	1.2	1.4	2.5[b]	2.1[b]	2.0[b]	1.4[b]
Orchardgrass	0.9	0.9	0.7	0.7	0[b]	0[b]	0[b]	0[b]	1.5	2.7	1.8	3.4
Russian wildrye	0.5	0.2	0.4	0.2	1.1	3.3	0.8	4.6	0.7[b]	0.3[b]	0.4[b]	0.3[b]
Thickspike wheatgrass	0	0	0	0	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
Forbs												
Alfalfa	2.5	2.9	1.4	1.8	0.1	0.2	0.2	0.1	1.1	0.6	0.6	0.6
Blue flax	0.2	0.7	0.4	0.8	0.7	3.5[a]	0.5	1.1	0.3	0.2	0.3	0.3
Small burnet	3.5	2.9	2.0	1.8	0[b]	0[b]	0[b]	0[b]	2.2	7.7	2.6	22.4
Western yarrow	0.4[b]	0.5[b]	0.3[b]	0.4[b]	14.1[ab]	2.4[b]	8.4[ab]	1.0[b]	1.7[b]	0.6[b]	3.0[b]	1.1[b]

Seed mix Species	Benson B				Cass Creek			
	UC BLM WSA	C BLM Non-WSA	UC BLM WSA	C BLM Non-WSA	UC BLM WSA	C BLM Non-WSA	UC BLM WSA	C BLM Non-WSA
	- - - Cover (%) - - -		Density (plants/m^2)		- - - Cover (%) - - -		Density (plants/m^2)	
Grasses								
Mountain brome	0.1	0[b]	0.2	0[b]	0.4	0.8[b]	0.4	1.4
Slender wheatgrass	7.0[a]	0[b]	5.6	0[b]	0.7	1.7[b]	0.7	2.0[b]
Crested wheatgrass	0.1[b]	4.3[a]	0.1[b]	7.2[a]	4.2[b]	5.1	4.4[b]	6.4
Intermediate wheatgrass	0[b]	1.9[a]	0[b]	1.4[a]	1.3[b]	3.1	1.0[b]	2.4
Orchardgrass	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0.1[b]
Russian wildrye	0[b]	3.3[a]	0[b]	4.6[a]	0.7[b]	2.2[a]	0.1[b]	0.3[a]
Thickspike wheatgrass	0	0[b]	0	0[b]	0	0[b]	0	0[b]
Forbs								
Alfalfa	0[b]	0.2	0[b]	0.1	0.9[b]	1.2	0.4[b]	0.5
Blue flax	0.2	3.5[a]	0.2	1.1[a]	0.3	0.2	0.3	0.2
Small burnet	0[b]	0[b]	0[b]	0[b]	0[b]	1.1[b]	0[b]	0.6[b]
Western yarrow	14.6[a]	2.4[b]	10.0[a]	1.0	15.7[a]	3.8[b]	12.0[a]	2.0[b]

[a] Significantly higher than other treatment ($p<0.05$)
[b] Not designated to be seeded on that treatment at that site

was true at the Coyote site. At the Benson A site, western yarrow was the dominant forb and was not designated to be seeded on either the unchained or chained areas (table 4). Higher establishment in the unchained than chained area may be a result of a greater number of seeds that were applied or drifted onto the unchained than chained area, a result of excessive seed burial on the chained area, or a result of both factors. At the Coyote site, the dominant forb was small burnet (*Sanguisorba minor*) and its establishment was apparently favored by chaining (table 4). Small burnet had similar density and cover on both chained and unchained areas at the Aspen site (table 4). Two accessions of small burnet were seeded for a total of 2.2 kg/ha at the Coyote site (UDWR high elevation mix) compared to only one accession seeded at 1.3 kg/ha (UDWR low elevation mix) at the Aspen site (table 1).

For the Cass Creek and Benson B sites seeded with the BLM WSA mix on unchained areas and seeded with the BLM non-WSA mix on chained areas, there were significant site, chaining treatment, and interaction effects (table 3). Perennial grass density was higher on chained than unchained areas at both sites, but cover was greater on chained areas only at the Cass Creek site (fig. 9). Both unchained and chained areas at these sites were seeded at a similar rate for perennial grasses (table 1) (10.5 kg/ha for unchained and 10.8 kg/ha for chained areas), but were seeded with different species. Therefore, we cannot determine if greater grass establishment on chained areas was a result

Table 5—Relative cover (percent) on seeded fire rehabilitation sites on the Henry Mountains, Utah.

Sites	Aspen Creek UDWR	Benson BLM	Benson	Cass Creek	Coyote Creek UDWR
			BLM WSA-unchained		
Seeding mix	low	non-WSA	BLM non-WSA-chained		high
Unchained					
Dominant perennial grasses					
Crested Wheatgrass	7.2	2.7	0.1	4.2	5.7
Intermediate Wheatgrass	2.4	1.6	0.01	1.3	2.5
Slender Wheatgrass	1	2.7	7	0.7	0.3
Total seeded grass cover	12.3	8.1	7.4	7.5	13.3
Dominant perennial forbs					
Western Yarrow	0.4	14.1	14.6	13.7	1.7
Blue Flax	0.2	0.7	0.2	0.3	0.3
Alfalfa	2.5	0.1	0.01	0.9	1.1
Small Burnet	3.5	0	0	0	2.2
Total seeded forb cover	7.4	15.2	14.9	16.9	5.5
Total seeded shrub cover	2.1	0.1	0.02	0.1	0.1
Chained					
Dominant perennial grasses					
Crested Wheatgrass	3.2	4.3	4.3	5.1	2.6
Intermediate Wheatgrass	4.3	1.9	1.9	3.1	2.1
Slender Wheatgrass	0.6	0	0	1.7	2.5
Total seeded grass cover	10.9	9.4	9.4	17.7	13.5
Dominant perennial forbs					
Western Yarrow	0.5	2.4	2.4	3.8	0.6
Blue Flax	0.7	3.5	3.5	0.2	0.2
Alfalfa	2.9	0.2	0.2	1.2	0.6
Small Burnet	3	0.01	0.01	1.1	7.7
Total seeded forb cover	8.2	6.2	6.2	6.4	9.4
Total seeded shrub cover	2.8	0.02	0.02	0.3	0.1

of chaining, associated with use of more successful species, or both (table 4).

On the Cass Creek and Benson B sites, seeded perennial forb density and cover were greater on unchained than chained areas (fig. 9). Western yarrow was the dominant forb encountered on these sites on both unchained and chained areas, even though it was not designated to be seeded on the chained areas (table 4). Greater establishment of yarrow on the unchained areas at these sites may be a result of chaining decreasing its establishment, but is more likely because the number of seeds that landed there by drift or overlap was much less than landed on the unchained area where it was designated to be seeded. Chaining could have excessively buried some of the yarrow seeds that landed in the chained area.

Several researchers have reported that predation (Nelson and others 1970), desiccation, insufficient soil contact, and lack of root penetration reduce establishment of plants from uncovered seeds (Vallentine 1989; Winkel and others 1991). Chaining may help bury seeds and increase water intake by loosening the soil surface and increasing porosity, aeration, and water infiltration (Cluff and others 1983; Wood and others 1982). Increased water infiltration may provide an extended period of available water for the seeds. Conversely, chaining covers seeds at various depths, and emergence of seedlings can be inhibited by excessive burial (Lawrence and others 1991; Vallentine 1989). Although chaining may be beneficial or detrimental at times, the amount of precipitation during critical growing periods is what most determines the success of revegetation on semi-arid zones (Call and Roundy 1991). High post-seeding spring precipitation resulted in successful plant establishment for fire rehabilitation on unchained and chained areas in this study. MacDonald (1999) also found chaining to be unnecessary for successful seedling establishment at elevations higher than 2,000 m. However, Ott and others (2003) found chaining was critical to success of aerially seeded fire rehabilitation sites at elevations under 1,800 m in central Utah.

Species Comparisons

Cover and relative cover of different species varied among sites and treatments in 2005, and some species were evident on sites and treatments where they were not included in the seed mix (tables 4 and 5). For example, at the Cass Creek site, Hycrest crested wheatgrass (*Agropyron cristatum* x *Agropyron desertorum*) had 4.2 percent cover on the WSA unchained treatment and western yarrow showed 3.8 percent cover on the chained treatment even though these species were not included in the seed mixes for these respective treatments at this site (tables 1 and 4).

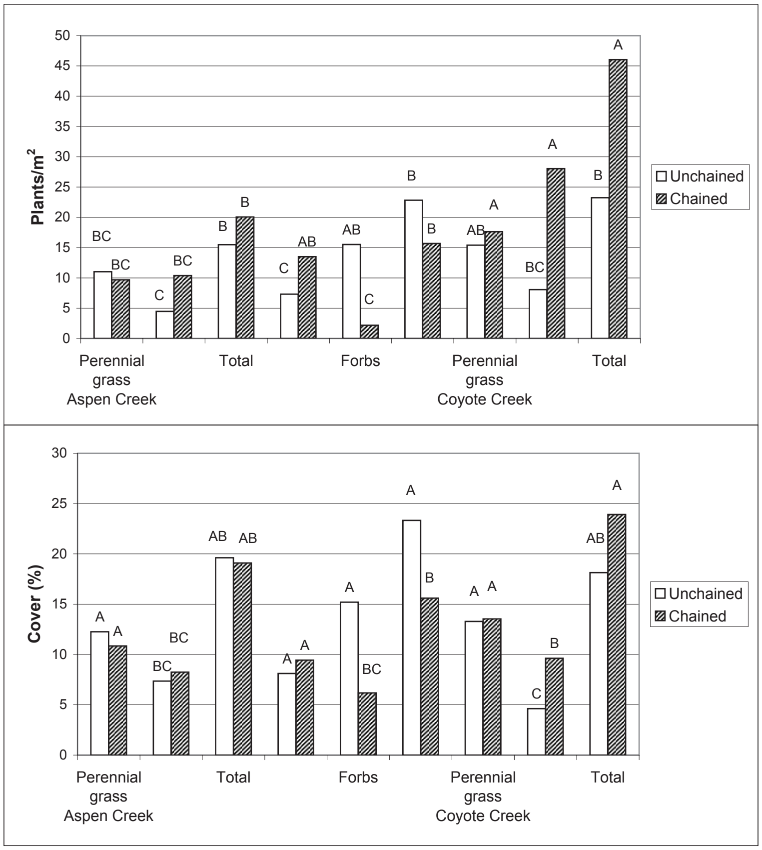

Figure 8—Density and cover of species seeded on intensively-sampled unchained and chained fire rehabilitation sites on the Henry Mountains, Utah, in 2005. Pairs of bars with different letters are significantly different ($p < 0.05$).

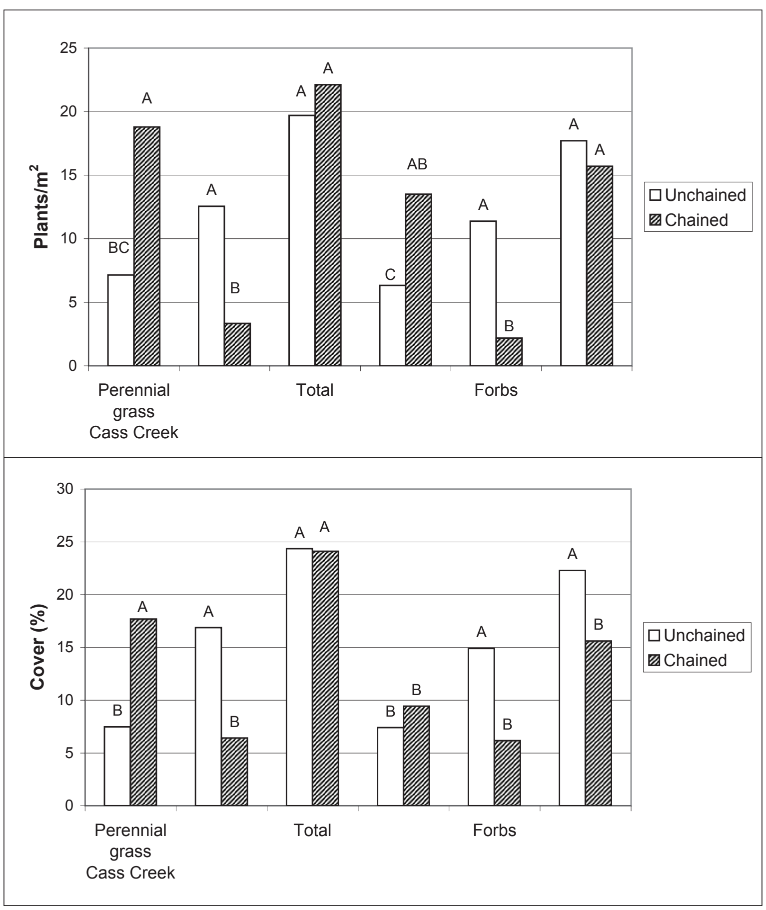

Figure 9—Density and cover of species seeded on intensively-sampled unchained and chained fire rehabilitation sites on the Henry Mountains, Utah, in 2005. Pairs of bars with different letters are significantly different ($p < 0.05$).

Table 6—Numbers of species seeded and encountered on fire rehabilitation sites on the Henry Mountains, Utah. Some species seeded in adjacent areas were encountered.

Sites Seeding mix	Aspen Creek UDWR low	Benson BLM non-WSA	Benson BLM WSA-unchained BLM non-WSA-chained	Cass Creek	Coyote Creek UDWR high
Perennial grasses					
Seeded in mix					
Unchained	8	5	4	4	8
Chained	8	5	5	5	8
Seeded in mix and encountered					
Unchained	6	4	3	3	6
Chained	6	4	4	4	6
Not seeded in mix but encountered					
Unchained	2	5	4	7	4
Chained	7	1	1	7	3
Total encountered					
Unchained	8	9	7	10	10
Chained	13	5	5	11	9
Perennial forbs					
Seeded in mix					
Unchained	6	2	2	2	9
Chained	6	2	2	2	9
Seeded in mix and encountered					
Unchained	4	2	2	2	6
Chained	4	2	2	2	6
Not seeded in mix but encountered					
Unchained	1	2	2	2	0
Chained	1	3	3	2	0
Total encountered					
Unchained	5	4	4	4	6
Chained	5	5	5	4	6
Shrubs					
Seeded in mix					
Unchained	2	1	0	0	1
Chained	5	1	1	1	4
Seeded in mix and encountered					
Unchained	1	0	0	0	1
Chained	2	1	1	1	2
Not seeded in mix but encountered					
Unchained	1	1	2	1	1
Chained	0	0	0	2	0
Total encountered					
Unchained	2	1	2	1	2
Chained	2	1	1	3	2

Occurrence of seeded species on sites or treatments where they were not included in the designated seed mix may be explained by close proximity of the different sites or treatments and overlap or drift of the aerial-seeded mixes.

Where crested wheatgrass was included in both the chained and unchained seed mixes, its cover on these treatments varied by site. Crested wheatgrass had lower cover percentages on chained than on unchained treatments at the Aspen and Coyote Creek sites, but greater cover on the chained than unchained treatment at the Benson A site (table 4). Chaining may have removed some residual plants at the Aspen Creek sites as already mentioned. The seeding rate of crested wheatgrass was higher at the Benson A site (BLM non-WSA mix, 2.8 kg/ha) than that of both the Aspen site (UDWR low elevation mix, 0.6 kg/ha) and the Coyote Creek site (UDWR low elevation mix, 1.1 kg/ha). Densities on both unchained and chained treatments at all sites where crested wheatgrass was seeded were high, and this species is considered to be successfully established on both treatments.

Density and cover of intermediate, pubescent (*Thinopyrum intermedium*), slender (*Elymus trachycaulus*) wheatgrasses, and Russian wildrye (*Psathyrostachys juncea*), though not significantly different between treatments when analyzed separately, all had higher mean density and cover for chained than unchained treatments when they were seeded at the same rate on both treatments (table 4). Blue flax (*Linum lewisii*) had higher cover on chained than unchained treatments at the Benson A site where it was seeded at the same rate on both treatments (table 4). Blue flax has a much larger seed than yarrow and might have greater seed coverage with than without chaining. At this same site, slender wheatgrass had higher cover and density on the unchained than chained treatment (table 4). It is not clear whether chaining directly reduced its establishment, or if greater establishment and possible interference of other seeded grasses on the chained area reduced its establishment there. Blue flax and small burnet appear to have benefited from chaining on some sites, while western yarrow successfully established without chaining. Yarrow had the highest cover of any seeded species on the WSA unchained sites, and produced 2.4 to 3.8 percent cover on the chained treatments at the Benson B and Cass Creek sites, even though it was not included in the seeding mix. During aerial seeding, its small seeds could easily have blown across the road that formed the boundary between the WSA unchained and non-WSA chained treatments. Its small seeds are also well-suited to broadcasting on sites where rocks and the loose, dioritic surface soil of the Henry Mountains provide safe sites or shallow burial for germination. Light is recommended to germinate yarrow for propagation purposes and it is recommended for shallow seeding <6 mm (Stevens and Monsen 2004). Establishment of small-seeded species like yarrow from aerial broadcasting is usually only successful when precipitation is consistent enough to provide available soil moisture for germination near the surface soil for a week or more. Little or no seed burial and a wet spring following seeding must have encouraged high germination of yarrow on unchained treatments.

Blue flax was seeded on both unchained and chained areas at all extensively and intensively sampled sites. On the extensively samples sites, it had slightly greater density (plants/m^2) on chained (0.54 ± 0.1) than unchained (0.29 ± 0.1) areas ($p < 0.0511$). On two of the intensively sampled sites (Benson A and Benson B), it had higher cover on chained than unchained areas (table 4). Blue flax establishment appears to be benefited by chaining.

Mountain big sagebrush was included in the UDWR low and high elevation mixes, but only a few seedlings where found on both the intensively and extensively sampled sites. Other seeded shrubs also had limited establishment. Establishment of shrubs in large-scale direct seedings on semi-arid rangelands continues to be a challenge.

Conclusions

Aerial seeding was successful in this study without chaining, but these results may not apply on lower elevation sites or on similar sites in years with lower post-seeding precipitation. On rehabilitation sites that are at high elevations (>1900 m) and receive high post-seeding precipitation, land management agencies may save the cost of chaining. Yet, precipitation is not predictable. Ott and others (2003) found that aerially seeded fire rehabilitation sites at lower elevations (<1,900 m) and in lower precipitation zones had limited seeded plant cover and were dominated by annual weeds. Seed burial and the microtopographic depressions resulting from chaining should increase time of available water, enhance germination and seedling survival under marginal precipitation. Seedbed modifications in semi-arid environments do not ensure revegetation success on dry years, may not be necessary on wet years, but could make the difference between success and failure in intermediate years (Winkel and Roundy 1991).

Confounding of seed mix with chaining treatment in this study limits the making of strong conclusions about the need for chaining to successfully establish certain species or functional groups. Although chaining increased grass density on the Benson A site, it did not significantly affect cover on this site, nor did it significantly increase seeded grass cover or density on the Aspen and Coyote Creek sites, which were also seeded with the same grass species on both unchained and chained treatments. Density is usually a more important measure than cover for determining seeding success, because if enough plants are established, they can grow and increase cover over time. Grass establishment is especially important to the Henry Mountains for forage and soil conservation. Chaining was associated with greater seeded grass cover and density on seven extensively sampled sites, but this may have been more a result of the species seeded on the chained areas than a result of chaining itself. Both chained and unchained treatments seeded with introduced grasses had successful plant establishment. Chained areas at the Benson B and Cass Creek sites had greater seeded grass densities and cover than unchained WSA areas, but the chained areas were seeded with introduced grasses known to establish well, while the unchained WSA areas were seeded with native grasses. Blue flax was seeded on both unchained and chained areas at all extensively sampled and intensively sampled sites. Generally higher density of blue flax on chained than unchained treatments suggests that its establishment was benefited by chaining. Western yarrow was the dominant forb encountered on unchained and chained treatments and established much better than blue flax, even though it was only seeded on the unchained WSA area. Except for establishment of western yarrow and blue flax, establishment of other forbs and shrubs was limited.

Comparison of unchained and chained plant establishment using the same seed mixes on each site would allow stronger conclusions about the effects of chaining on revegetation success. Also, monitoring seeding success on unchained and chained sites using the same seed mix would allow determination of which species establish best in the seeded environment.

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