The Effect of Herbaceous Species Removal, Fire, and Cheatgrass (*Bromus tectorum*) on Soil Water Availability in Sagebrush Steppe

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Abstract—Over the past several decades, cheatgrass (*Bromus tectorum*) has been continually expanding in the sagebrush steppe ecosystem. There has been very little research that examines why cheatgrass is able to invade these communities. To determine the effects of herbaceous vegetation removal and fire on available water for cheatgrass invasion, as well as effects of cheatgrass itself, we measured spring soil moisture and vegetation cover on nine sites in Nevada and Utah. Total time of soil water availability was calculated for 1 April through 30 June in 2002 and 2003 on plots that were left intact, sprayed with an herbicide to kill all herbaceous vegetation, burned, or both burned and sprayed in 2001. Soil water was also measured on subplots either left unseeded or seeded to cheatgrass in fall 2001. The number of days that soil moisture was available increased with site elevation and annual precipitation. Time of surface soil (1 to 3 cm) water availability was increased by 12 days in a wetter year (2003) compared to a drier year (2002) and was not significantly affected by disturbance. Time of subsurface soil water availability (13 to 15 and 28 to 30 cm) was increased more by disturbance than seasonal precipitation. Vegetation removal plots had 7 days longer subsurface soil water availability than intact plots the first year after removal. Burned plots had 4 to 6 days longer subsurface soil water availability than unburned plots. Cheatgrass establishment was limited, especially at the Utah sites, and did not significantly affect soil water availability. Soil water resources may be increased by disturbance, higher annual precipitation, or both and thereby facilitate weed invasion.

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Introduction

The spread of cheatgrass (*Bromus tectorum*) has displaced much of the native vegetation throughout the west. Cheatgrass was introduced to the Great Basin region at the end of the 19th century and in just 20 to 30 years had spread throughout most of the western United States (Knapp 1996; Mack 1981). Today it is hard to find a big sagebrush (*Artemisia tridentata*) community that has not been invaded by cheatgrass (Knapp 1996). Cheatgrass invasion in the Great Basin has changed the fire frequency from 50 to 200 years to 3 to 5 years, resulting in cheatgrass-dominated communities (Whisenant 1990). But how does this plant or any other weed invade a community?

Elton (1958) argued that communities with lower plant diversity were most susceptible to invasion. Levine and D'Antonio (1999) suggested that this is not necessarily the case. Their review of community diversity and invasibility indicated that more diverse communities were often more susceptible to invasion than less diverse communities. Stohlgren and others (1999) also found that communities with higher diversity were more invasible and that invasion is more closely related to the amount of resources that were available in the community. Other studies have shown that nutrient-enriched plots were dominated by weedy annuals (Carson and Barrett 1988; Foster and Dickson 2004). Davis and others (2000) observed that any factor leading to increased availability of limiting resources increases susceptibility of a community to invasion.

Potentially limiting resources to plant growth such as light, water, and nutrients plays a large part in community composition (Tilman 1986). Resources fluctuate annually, seasonally, and spatially. Susceptibility of a community to invasion varies with these fluctuations in resource availability (Davis and others 1998; Davis and others 2000). Disturbance may increase resources by reducing resource use by pre-disturbance vegetation. Disturbance also leaves an open space for invasion (Burke and Grime 1996).

In the Great Basin, water is a major limiting resource to plant growth and development, and greatly influences plant community composition (Ceballos and others 2002; Coronato and Bertiller 1996; Daubenmire 1972; Fowler 1986). Soil moisture changes over time according to the amount of precipitation and evapotranspiration, which varies depending on the season, topography, vegetation, soil depth and texture, and land use history (Coronato and Bertiller 1996; Wythers and others 1999). In semi-arid climates like the

Great Basin, soil water recharge occurs during the winter months usually in the form of snow. Precipitation in the late spring and summer is very sporadic with long dry periods between precipitation events (Cable 1980). This leads to a wide variation in the amount of soil moisture that is available over time. Other variations in soil moisture availability come from the type and amount of vegetation that is present. Vegetation affects infiltration as well as evapotranspiration. The loss of vegetation from grazing, fire, or other disturbances may decrease infiltration and transpiration and increase evaporation (Cable 1980). Growth form also affects transpiration. Woody species use water from throughout the soil profile, whereas annual plants only use water from the upper most portions of the soil profile (Daubenmire 1968). Soil moisture loss through transpiration is also highest at the time that the vegetation is actively growing. Changes in precipitation, vegetation cover, or disturbance can increase the availability of soil moisture and may play a large role in the susceptibility of a community to invasion.

Several wet years in the early 1980s were associated with an increase of cheatgrass invasion in salt desert communities (Meyer and others 2001). Soto and Diaz-Fierros (1997) found that after a fire burns gorse (*Ulex europaeus*, L.) shrubland, more precipitation actually hit the ground, but lack of vegetation resulted in increased evaporation and decreased transpiration. This changed how the soil profile dried out. The upper portion of the soil profile dried very quickly while the lower portion took longer to dry out. Other studies have shown that burning actually decreases the amount of soil moisture that is available (Daubenmire 1968; Melgoza and others 1990; Redmann 1978). Grazing can also change the vegetation in a community; however, one study showed that grazing did not have an effect on soil moisture (Coronato and Bertiller 1996). Melgoza and others(1990) also found that the upper soil profile dries out more rapidly on sites dominated by cheatgrass.

Our objectives were to determine the effects of vegetation disturbance on the number of days that water was available in the soil (matric potential > –1.5 MPa) across an elevational gradient for big sagebrush communities in the Great Basin. We hypothesized that the time of available water should be extended as elevation increases with increasing precipitation, and the loss of vegetation associated with disturbance should result in a longer period of available water as a result of decreased transpiration. The presence of cheatgrass after disturbance may also decrease soil moisture availability. To address these questions, available soil moisture was measured at three different depths under three different treatments for a period of 2 years, focusing on the April through June growing period.

Methods

Study Sites

There were five study sites selected in Utah and four selected in Nevada. We selected sites that had an intact native perennial understory. In Nevada, one site was located in a crested wheatgrass (*Agropyron cristatum* (L) Gaertn.) community and three sites were located in big sagebrush communities along an elevational gradient. A crested wheatgrass site and three big sagebrush sites similar to the Nevada sites were also selected in Utah. The fifth Utah site was located in a grass community dominated by bottlebrush squirreltail (*Elymus elymoides* (Raf.) Swezey) (table 1).

The four Nevada study sites are located on the Humbolt-Toiyabe National Forest at 39º north latitude, 117° 30’ west longitude. The crested wheatgrass site was located in an area that was cleared in the early 1960s and was reseeded with crested wheatgrass. The five Utah study sites are located in Tooele County on land managed by the Bureau of Land Management at 40° north latitude, 112° west longitude.

The squirreltail and crested wheatgrass sites in Utah and the crested wheatgrass site in Nevada have a few scattered Wyoming big sagebrush plants. The dominant plants on the lower elevation site in Nevada are Wyoming big sagebrush, Sandberg bluegrass (*Poa secunda* J. Presl.), and needle and threadgrass (*Hesperostipa comata* (Trin. & Rupr.) Barkworth). The middle elevation site in Nevada is dominated by mountain big sagebrush and Sandberg bluegrass. The upper elevation site in Nevada is dominated by mountain big sagebrush, Idaho fescue (*Festuca idahoensis* Elmer), and western wheatgrass (*Pascopyrum smithii* (Rybd.) A. Love). In Utah, the lower elevation site is dominated by Wyoming big sagebrush, bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Love) and galleta (*Pleuraphis jamesii* Torr.). The middle elevation site in Utah is dominated by mountain big sagebrush, bluebunch wheatgrass, and Fendler’s bluegrass

Table 1—Description of study sites in Utah and Nevada.

State	Site	Elevation (m)	Soil texture	Soil classification
Nevada	Crested Wheatgrass	2065	sandy loam	Xereptic Haplodurid
	Lower Wyoming big sagebrush	1960	sandy loam	Xeric Haplocambid
	Middle mountain big sagebrush	2190	sandy loam	Typic Haploxeroll
	Upper mountain big sagebrush	2380	loam	Xeric haplocryoll
Utah	Bottlebrush squirreltail	1608	loam	Xeric Haplocalcid
	Crested Wheatgrass	1628	gravelly sandy loam	Xeric Haplocalcid
	Lower Wyoming big sagebrush	1710	gravelly sandy loam	Petrocalcic Palexeroll
	Middle mountain big sagebrush	2085	gravelly loam	Lithic Calcixeroll
	Upper mountain big sagebrush	2274	gravelly loam	Lithic Calcixeroll

(*Poa fendleriana* (Steud.) Vasey). The dominant plants of the upper elevation site in Utah are mountain big sagebrush, Fendler's bluegrass, spike fescue (*Leucopoa kingii* (S. Wats.) W. A. Weber), and Columbia needlegrass (*Achnatherum nelsonii* (Scribn.) Barkworth.

Experimental Design and Treatments

We imposed three disturbance treatments including chemical removal of understory vegetation, burning, and seeding of cheatgrass. Treatments were imposed on each of the four sites in Nevada and five sites in Utah. All combinations of understory vegetation removal (0 and 100 percent) and fire (unburned and burned) treatments were applied to determine combined and separate effects of vegetation removal and fire on soil water availability. These treatments resulted in a potential matrix of vegetation components (table 2). On control plots, both the understory and shrub components are still present. The herbaceous vegetation removal plots only have the shrub component, the burn plots lose the shrub component, and the burned plots that have also had the herbaceous vegetation removed lose both the shrub and understory components. Treatments were applied on three replicates of each treatment combination in a randomized block design at each site. The cheatgrass seeding treatment was applied as a subplot within each treatment combination. Each main plot was circular and had an area of 36.30 m^2 (r = 1.7 m). Understory vegetation removal plots were treated with 170.5 ml of Roundup® mixed in 4.5 L of water during active spring growth in 2001. The plots were then either left unburned or burned in early November 2001. Plots were burned in 4-m diameter burn barrels after adding 4.5 kg of weed-free straw for consistent fuel loading (Korfmacher and others 2003). Subplots 1.5 cm x 0.75 cm were overseeded with cheatgrass at a rate of 625 seeds/m^2 within each treatment plot. Soil moisture sensors were installed inside and outside of these seeded subplots in summer 2001.

Soil Moisture

Delmhorst, Inc. GB-1 gypsum blocks were buried at three depths, 1 to 3, 13 to 15, and 28 to 30 cm to measure soil water matric potential on each unseeded and seeded subplot within each vegetation removal-burn treatment plot combination. Measurements were taken every minute and hourly averages recorded by CR-10 and CR10X Campbell Scientific, Inc. microloggers. Resistance data were then converted into MPa. Then every hour that had a matric potential >–1.5 MPa was summed and divided by 24 to obtain the number of days that water was available. Hourly precipitation totals and air temperature averages were also recorded by microloggers at each site. Data were collected for 2 years after treatment.

Vegetation Sampling

Vegetation was sampled during the summers of 2002 and 2003. Each treatment plot was sampled with eight, 0.25 m^2 quadrats. A modified Duabenmire (1959) cover class method with eight cover classes was used to estimate cover. The eight cover classes are: (1) 0.01 to 1 percent, (2) 1.1 to 5 percent, (3) 5.1 to 15 percent, (4) 15.1 to 25 percent, (5) 25.2 to 50 percent, (6) 50.1 to 75 percent, (7) 75.1 to 95 percent, and (8) 95.1 to 100 percent. Cover was estimated by species and by type of ground cover (bare ground, litter, rock, pavement, and cryptogamic crusts). Cover was estimated by selecting the smallest cover class in which all of one species or cover type would fit. Then, for each species or cover type, the midpoint for that cover class was taken and averaged with the midpoints from the seven other quadrat subsamples from that plot. Individuals of each species within the 0.25 m^2 quadrats were counted to determine density.

Analysis

Mixed model analysis (Littell and others 1996) was used to compare vegetation variables and time of available water for 1 April through 30 June of 2002 and 2003. Year and vegetation removal, fire, and seeding treatments were considered fixed variables, while site and replication were considered random. Two separate sets of analyses were done for both the vegetation data and the available water data. Vegetation was then split into three different categories: (1) total vegetation, (2) perennial herbaceous vegetation, and (3) annual vegetation. The first analysis compared the six big sagebrush sites that were along the elevation gradient, while the second analysis compared the lowest elevation big sagebrush sites in Nevada and Utah and the crested wheatgrass and bottlebrush squirreltail sites. These five lower sites were similar in elevation but varied by vegetation. Total time of soil water availability was analyzed separately for each soil depth. Best linear unbiased predictions (BLUPS) were calculated to compare treatment effects by site (Littell and others 1996).

Table 2—Presence or absence of vegetation after treatment.

	Control	Vegetation removal	Fire	Vegetation removal + fire
Understory vegetation	+	–	+/– [a]	–
Sagebrush	+	+	–	–

[a] Depends on particular species response to fire. Most herbaceous species survive cool-season, low intensity fire.

Results

Precipitation

Overall precipitation from 1 October to 30 June increased as elevation increased (figs. 1a and 1b). The exception to this occurred in 2002 to 2003 on the middle site in Nevada, which had higher precipitation than the upper Nevada site. Precipitation was lower in 2001 to 2002 than 2002 to 2003 with the exception of the Nevada crested wheatgrass site, which was drier in 2002 to 2003. When comparing the precipitation that fell in these two years to the 30-year average from nearby weather stations, 2001 to 2002 was well below average and 2002 to 2003 was a little below average.

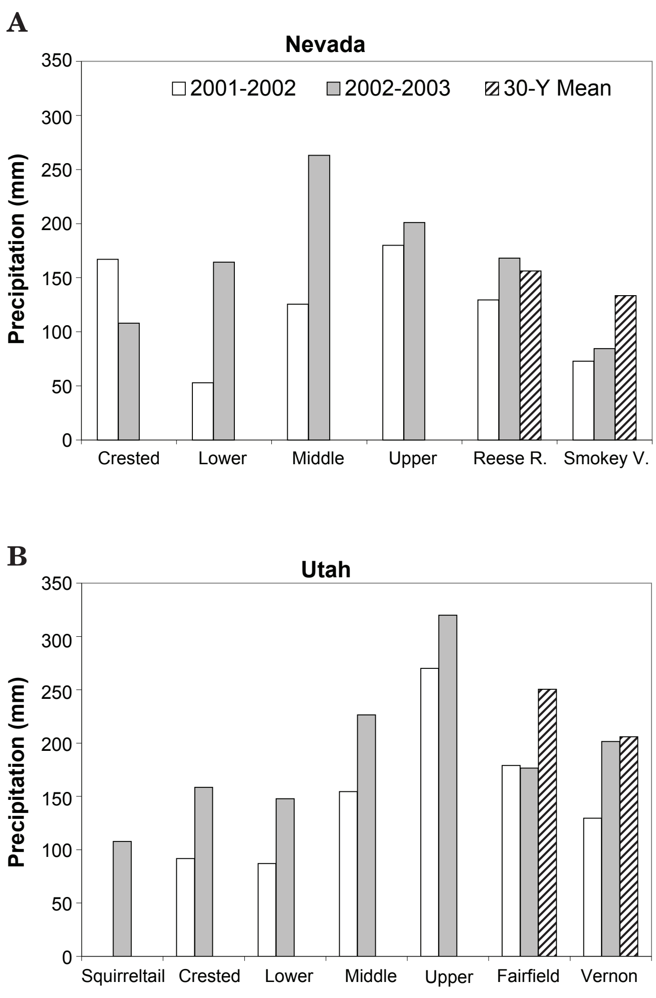

Figure 1—Precipitation measured between 1 October and 30 June at 9 big sagebrush sites in (A) Nevada and (B) Utah. Reese River, Smokey Valley, Fairfield, and Vernon precipitation data were obtained from long-term climate stations (Western Regional Climate Center).

Big Sagebrush Sites

Vegetation—Total vegetation, perennial vegetation, and annual vegetation cover all varied significantly ($p < 0.01$) by year and by removal treatment. Total vegetation also varied significantly by burn treatment ($p < 0.01$) and by the interaction of year by burn treatment ($p < 0.01$). Perennial vegetation cover also varied with the interaction of year by removal treatment ($p < 0.01$). Vegetation cover was higher in 2003 than 2002 for all three vegetation groups (fig. 2). Total and perennial vegetation cover was significantly lower on removal plots than intact plots. Annual vegetation cover however, was significantly higher on removal than intact plots (fig. 3). Total vegetation cover was the only variable that was significantly affected by burning. In 2002 total vegetation cover was similar on unburned and burned plots. In 2003, however, the unburned plots had higher total vegetation cover than the burned plots (fig. 4).

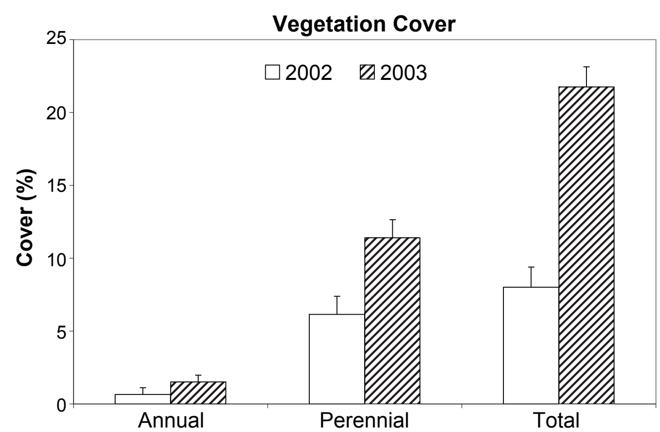

Figure 2—Vegetation cover measured in 2002 and 2003 at six sagebrush sites. Data categories are annual vegetation, perennial herbaceous vegetation, and total woody plus herbaceous vegetation.

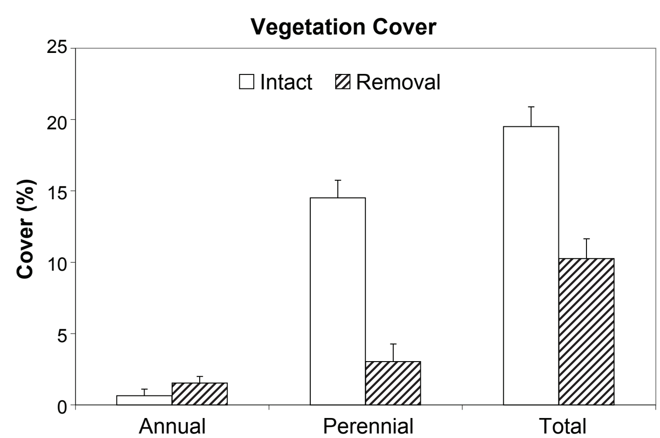

Figure 3—Cover of annual, perennial, and total woody and herbaceous vegetation on plots where herbaceous vegetation was left intact or removed at six big sagebrush sites.

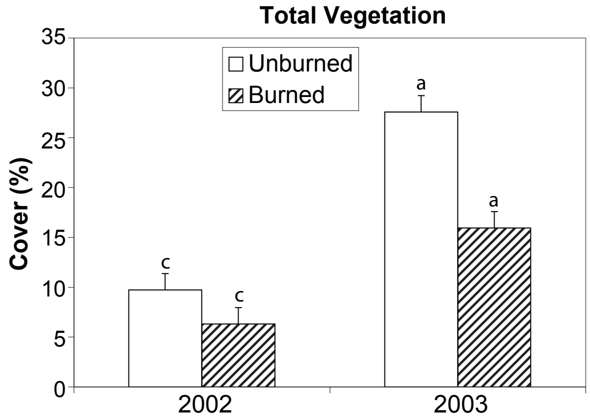

Figure 4—Total vegetation (herbaceous and woody) was measured in 2002 and 2003 on plots that were not burned or burned at six big sagebrush sites. Treatments with means not significantly different ($p < 0.05$) are labeled with the same letter.

Available Water—Total days of available water (estimated using BLUPs) increased as elevation increased (fig. 5). This was mainly true for all three depths. The only exception was the lowest elevation big sagebrush site in Utah had slightly more days of available water than the middle sagebrush site at 1 to 3 cm.

At 1 to 3 cm, the only significant ($p < 0.01$) was year. In 2002, the total time of available water was 42 days and in 2003 it was 53 days. No other treatment effects were significant at this depth.

At the 13 to 15 cm depth, total days of available water varied significantly by year, removal treatment, burn treatment, and by the interaction of year by removal treatment, and year by burn treatment. In 2002, the first growing season after the treatment, the intact plots had 7 fewer days of available water than the removal plots (fig. 6a). In 2003 there was not a significant difference between the removal and intact plots. Similar results occurred on the burned and unburned plots. The burned plots in 2002 had 6 more days of available water than the unburned plots, and in 2003 there was no significant difference between the burned and unburned plots (fig. 6b).

At 28 to 30 cm, the significant ($p < 0.01$) effects were removal and burn. The intact plots had 62 days of available water and the removal plots had 68 days of available water. The unburned plots had 63 days of available water and the burned plots had 67 days of available water.

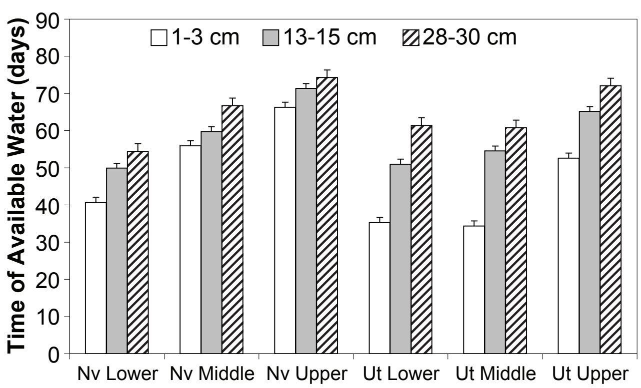

Figure 5—Total days of available soil moisture (soil matric potential > –1.5 MPa) measured at three soil depths between 1 April and 30 June at six big sagebrush sites.

Low Elevation Sites

Vegetation—Total and annual vegetation cover varied significantly both by year and removal ($p < 0.01$). Total vegetation cover also varied significantly ($p < 0.01$) by burn treatment. Perennial vegetation cover only varied significantly ($p < 0.01$) by removal. In 2002 both total and

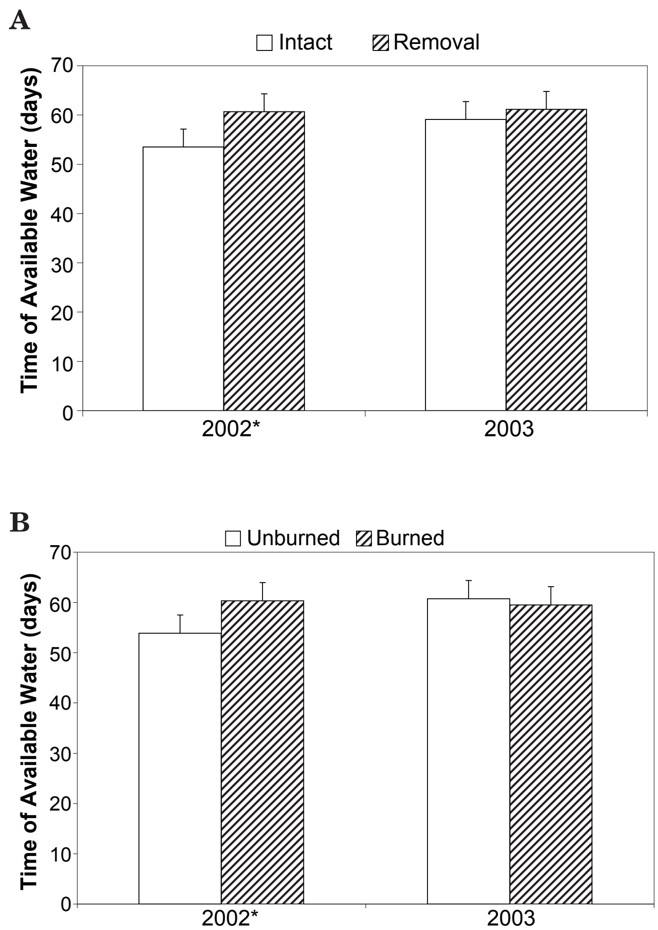

Figure 6—Total days of available soil moisture (soil matric potential > –1.5 MPa) on six big sagebrush sites at 13–15 cm between 1 April and 30 June 2002 and 2003 on plots where (A) herbaceous vegetation was left intact or removed and (B) vegetation was either not burned or burned. *Treatment was only significantly different ($p < 0.05$) in 2002.

annual vegetation cover was lower than 2003; however, perennial cover didn't differ significantly between years (fig. 7). Total and perennial vegetation cover was significantly higher on intact plots than removal plots, but annual vegetation cover was significantly lower on the intact than removal plots. The burn treatment only had a significant effect on the total vegetation, lowering vegetation cover on the burned plots by 3 percent. The unburned plots had a total vegetation cover of 10.4 percent and the burned plots had vegetation cover of 7.5 percent.

Available Water—The total days of available water for each of the low elevation sites differed little among sites (fig. 8). The total days of available water on the squirreltail site (at 1 to 3 cm) is the only measurement that was significantly higher than the others.

At 1 to 3 cm, the total days of available water were significantly different by year and by removal treatment. In 2002, the low elevation sites had 23 fewer days of available water than in 2003 (fig. 9). The total time of available water was also significantly shorter on intact plots compared to removal plots. Intact plots had 38 days of available water, whereas the vegetation removal plots had 40 days of available water.

Total days of available water at the 13 to 15 cm depth varied significantly by year, removal treatment, burn treatment, and by the interaction of year by removal treatment, and year by burn treatment. In 2002, intact plots had 10 fewer days of available water than removal plots; whereas, in 2003 the difference between intact and removal plots was not significant. Likewise, in 2002 the unburned plots had 6 fewer days of available water than the burned plots and there was no significant difference between the two treatments in 2003.

At the third depth, 28 to 30 cm, only year and removal were significant ($p < 0.01$) for total days of available water. There were 11 more days of available water in 2003 than in 2002 (fig. 9). The intact plots had 52 days of available water and the vegetation removal plots had 63 days of available water.

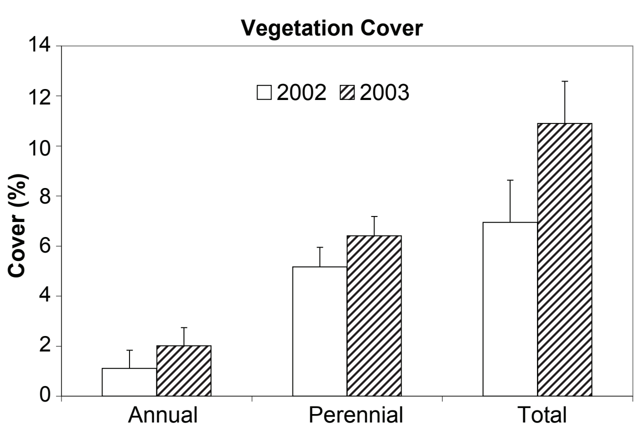

Figure 7—Annual, perennial, and total (herbaceous and woody) vegetation cover measured in 2002 and 2003 at five Wyoming big sagebrush zone sites.

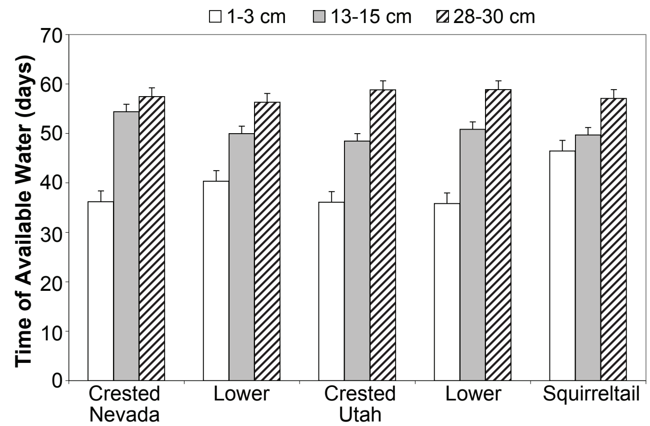

Figure 8—Total days of available soil moisture (soil matric potential > –1.5 MPa) measured at three soil depths between 1 April and 30 June at five Wyoming big sagebrush zone sites.

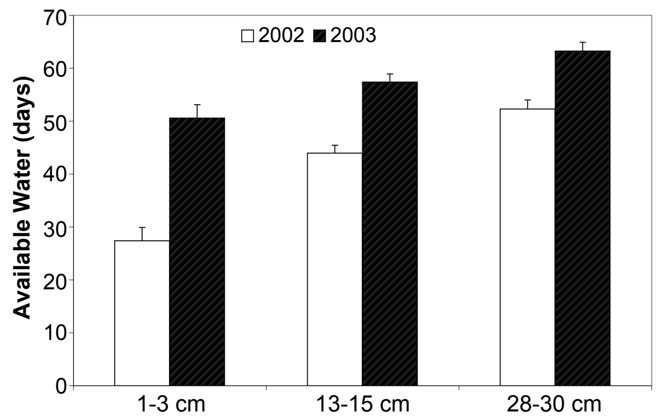

Figure 9—Total days of available soil moisture (soil matric potential > –1.5 MPa) measured at three soil depths in 2002 and 2003 between 1 April and 30 June at five Wyoming big sagebrush zone sites. *Depth with means significantly different ($p < 0.05$)

Discussion

Goldberg (1990) describes how the environment and plants both affect resources, which in turn affect associated plant growth and development. Soil water is affected by the environment through precipitation and evaporation and is also affected by the vegetation through transpiration and shading. If any of those factors change, soil moisture will change also. The soil water then affects the vegetation that is still present. The input of water through precipitation was much higher in 2003 than 2002, which resulted in an increase in both available water and vegetation cover. As elevation increased so did precipitation and the time of available water. When vegetation cover was decreased by disturbance, soil water was available for a longer period, probably due to decreased transpiration. Schlesinger and others (1987) found plots with vegetation harvested had higher available soil water than plots of intact vegetation. Coronato and Bertiller (1996) examined effects of grazing on soil moisture and found that soil moisture did not change significantly. They concluded that the loss of vegetation decreased transpiration but also increased evaporation, resulting in no net change in soil moisture.

Davis and others (1998) hypothesized that it is the net change in resources that affects the competition and the invasibility of a community. Foster and Dickson (2004) found that increasing the available water made the community more invasible. Increased resources over time increase the opportunity for the invader to establish and set seed (Booth 2003). In our study, annual vegetation cover was significantly higher in 2003 than 2002 on removal plots compared to intact plots. Both year and removal were important to increasing time of available water. Chambers and others (2007) examined cheatgrass establishment and production on these same plots. They found that cheatgrass establishment, biomass, and seed production were higher on removal plots and burned plots than on intact plots. Beckstead and Augspurger (2004) did a study where they removed vegetation cover in a shadscale (*Atriplex confertifolia)*-bunchgrass community and found that the vegetation removal plots had higher cheatgrass density and biomass.

At the 1 to 3 cm depth, the removal and fire treatments did not have a significant effect on the time of available water, however the variation by year was significant. In 2003, there were 12 more days of available water than 2002. During this same year, the burn treatment and the vegetation removal treatment only caused a 2-day increase in available water. Roundy and others (in progress) found that variation in annual weather affected wet thermal-time for cheatgrass germination more than vegetation removal or fire on these same plots. At the soil surface, seasonal precipitation had a greater effect on the time of available water than did disturbance treatments. Soil water inputs and outputs by precipitation and evaporation would be expected to have a greater effect on surface soil moisture than the presence or absence of vegetation as affected by disturbance.

Subsurface soil moisture is lost more slowly than that at the surface, with transpiration being the major process of water loss (Schwinning and Ehleringer 2001). At these lower depths, the effects of vegetation loss and fire were more evident. At the 13 to 15 cm depth, removal plots had 7 more days of available water than intact plots, while in 2003 there were only 3 more days of available water than in 2002. At the 28 to 30 cm depth, removal plots had 7 more days of available water than intact plots, burned plots had 4 more days of available water than unburned plots, and time of available water did not vary by year. Increase in surface soil moisture by increased precipitation provides more opportunity for cheatgrass to germinate, and the increase in subsurface soil moisture after disturbance allows cheatgrass to establish and set seed. Meyer and others (2001) found that irrigating near shrubs, where the ground is shaded, resulted in higher cheatgrass plant biomass than near non-irrigated shrubs. This provided the cheatgrass that germinated enough soil moisture to establish and set seed similar to increasing water through disturbance.

Removal and burn treatments had significant effects on soil moisture only during the first year after disturbance. However, disturbance resulted in lower vegetation cover both years after treatment. Both seasonal precipitation and vegetation cover were higher in 2003 than 2002. By 2003, understory vegetation that had been burned had grown back, shrubs that had not been burned were still present, and cover of annual grasses and forbs was higher on removal plots. The response of the vegetation to the treatments and precipitation in 2003 resulted in only a short-term effect of disturbance on time of available soil moisture.

In this study cheatgrass did not affect the time of available water. One possible reason for this is that cheatgrass was not seeded until late November 2001 and so cheatgrass establishment was relatively low especially on the Utah plots. The cheatgrass that did establish did not germinate until spring. Fall germination of cheatgrass might have had a greater affect on spring soil moisture by allowing greater development of roots and increased transpiration. Melgoza and others (1990) conducted a large-scale study that examined the effect of cheatgrass on soil moisture and found that the presence of cheatgrass did decrease the amount of soil moisture. Cheatgrass competition for soil moisture is a major factor in the failure of establishment for many desirable grasses, forbs, and shrubs (Young and others 1987). If germinating species do not have a long enough wet period for emergence and root elongation, seedlings will not survive (Abbot and Roundy 2003).

In this study, disturbance evidently decreased the amount of resource use resulting in a net increase in time of available soil moisture. As observed by Chambers and others (2007), the net increase in resources resulted in an increase of cheatgrass establishment and seed production. It also increased the cover of other annual grasses and forbs. The effects of disturbance on soil water resources in our study were highly dependent on seasonal precipitation inputs. Seasonal precipitation and weather conditions may be more important to cheatgrass invasion than disturbance. In our study annual weather fluctuations affected the time of water availability in the surface soil where germination occurs more than did disturbance. Roundy and others (in progress) found that sufficient wet thermal time accumulated for successful cheatgrass germination on these sites in spring and often in fall, with or without disturbance. The effect of disturbance and annual fluctuation on soil moisture in our study was only temporary, but it left the community vulnerable to invasion as resources fluctuated and increased.

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References

Abbott, L.B.; Roundy, B.A. 2003. Available water influences field germination and recruitment of seeded grasses. Journal of Range Management. 56: 56-64.

Beckstead, J.; Augspurger, C.K. 2004. An experimental test of resistance to cheatgrass invasion: limiting resources at different life stages. Biological Invasions. 6:417-432.

Booth, M.S.; Caldwell, M.M.; Stark, J.M. 2003. Overlapping resource use in three Great Basin species: Implications for community invasibility and vegetation dynamics. Journal of Ecology. 91: 36-48.

Burke, M.J.W.; Grime, J.P. 1996. An experimental study of plant community invasibility. Ecology. 77: 776-790.

Cable, D.R. 1980. Seasonal patterns of soil water recharge and extraction on semi-desert ranges. Journal of Range Management. 33: 9-15.

Carson, W.P.; Barrett, G.W. 1988. Succession in old-field plant communities: Effects of contrasting types of nutrient enrichment. Ecology. 69: 984-994.

Ceballos, A.; Martinez-Fernandez, J.; Santos, F.; Alonso, P. 2002. Soil-water behavior of sandy soils under semi-arid conditions in the Duero Basin (Spain). Journal of Arid Environments. 51: 501-519.

Chambers, J.C.;Roundy, B.A.; Blank, R.R.; Meyer, S.E.; Whittaker, A. 2007. What makes Great Basin sagebrush ecosystems invasible by *Bromus tectorum*? Ecological Monographs. 77(1): 117-145.

Coronato, F.R.; Bertiller, M.B. 1996. Precipitation and landscape related effects on soil moisture in semi-arid rangelands of Patagonia. Journal of Arid Environments. 34: 1-9.

Daubenmire, R. 1968. Soil moisture in relation to vegetation distribution in the mountains of northern Idaho. Ecology. 49: 431-438.

Daubenmire, R. 1972. Annual cycles of soil moisture and temperature as related to grass development in the steppe of Eastern Washington. Ecology. 53: 419-424.

Davis, M.A.; Wrage, K.J.; Reich, P.B. 1998. Competition between tree seedlings and herbaceous vegetation: Support for a theory of resource supply and demand. Journal of Ecology. 86: 652-661.

Davis, M.A.; Grime, J.P.; Thompson, K. 2000. Fluctuating resources in plant communities: A general theory of invasibility. Journal of Ecology. 88: 528-534.

Elton, C.S.1958. The ecology of invasions by animals and plants. London: Methuen.

Foster, B.L.; Dickson, T.L. 2004. Grassland diversity and productivity: the interplay of resource availability and propagule pools. Ecology. 85: 1541-1547.

Fowler, N. 1986. The role of competition in plant communities in arid and semiarid regions. Annual Review of Ecology and Systematics. 17: 89-110.

Goldberg, D.E. 1990. Components of resource competition in plant communities. In: Grace, J. B.; Tilman, D., eds. Perspectives on plant competition. San Diego, CA: Academic Press, Inc.: 27-49.

Knapp, Paul. A. 1996. Cheatgrass (*Bromus tectorum* L.) dominance in the Great Basin Desert. history, persistence, and influence to human activities. Global Environmental Change. 6: 37-52.

Levine, J.M.; D'Antonio, C.M. 1999. Elton revisited: A review of evidence linking diversity and invasibility. Oikos. 57: 15-26.

Littell, R.C.; Milliken, G.A.; Stroup, W.W.; Wolfinger, R.D. 1996. SAS system for mixed models. Cary, NC: SAS Institute.

Mack, R.N. 1981. Invasion of *Bromus tectorum* into western North America: An ecological chronicle. Agro-Ecosystems. 7: 145-165.

Melgoza, G.; Nowak, R.S.; Tausch, R.J. 1990. Soil water exploitation after fire: Competition between *Bromus tectorum* (cheatgrass) and two native species. Oecologia. 83: 7-13.

Meyer, S.E.; Garvin, S.C.; Beckstead, J. 2001. Factors mediating cheatgrass invasion of intact salt desert shrubland. In: McArthur, E.D.; Fairbanks D.J., comps. Proceedings: Shrubland ecosystem genetics and biodiversity. Proceedings RMRS-P-21. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 224-232.

Redmann, R.E. 1978. Plant and soil water potentials following fire in a northern mixed grassland. Journal of Range Management. 31: 443-445.

Roundy, B.A.; Chambers, J.C.; Meyer, S.E.; Whittaker, A. In progress. Fulfilling thermal time requirements for germination of cheatgrass: Seasonal effects of climate, elevation, and disturbance.

Schlesinger, W.H.; Fonteyn, P.J.; Marion, G.M. 1987. Soil moisture content and plant transpiration in the Chihuahuan Desert of New Mexico. Journal of Arid Environments. 12: 119-126.

Schwinning, S.; Ehleringer, J.R. 2001. Water use trade-offs and optimal adaptations to pulse-driven arid ecosystems. Ecology. 89: 464-480.

Soto, B.; Diaz-Fierros, F. 1997. Soil water balance as affected by throughfall in gorse (*Ulex europaeus*, L.) shrubland after burning. Journal of Hydrology. 195: 218-231.

Stohlgren, T.J. Binkley, D.; Chong, G.W.; Kalkhan, M.A.; Schell, L.D.; Bull, K.A.; Otsuki, Y.; Newman, G.; Bashkin, M.; Son, Y. 1999. Exotic plant species invade hot spots of native plant diversity. Ecological Monographs. 69: 25-46.

Trickler, D.L.; Hall, D.T. 1984. Soil survey of Fairfield-Nephi area, Utah. U.S. Department of Agriculture, Soil Conservation Service.

Tilman, D. 1986. Nitrogen-limited growth in plants from different successional stages. Ecology. 67: 555-563.

Western Regional Climate Center. [Online]. Available: www.wrcc.dri.edu\index.html.

With, K.A. 2002. The landscape ecology of invasive spread. Conservation Biology. 16: 1192-1203.

Whisenant, S.G. 1990. Changing fire frequencies on Idaho's Snake River Plains: Ecological and management implications. In: McArthur, E. Durant; Romney, Evan M.; Smith, Stanley D.; Tueller, Paul T., comps. Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 4-10.

Wythers, K.R.; Laurenroth, W.K.; Paruelo, J.M. 1999. Bare-soil evaporation under semiarid field conditions. Soil Science American Journal. 63: 1341-1349.

Young, J.A.; Evans, R.A.; Eckert, Jr., R.E.; Kay, B.L. 1987. Cheatgrass. Rangelands. 9: 266-270.