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LONG-TERM VEGETATION DYNAMICS IN A CUT WESTERN JUNIPER WOODLAND

Jonathan D. Bates^{1,2,4}, Richard F. Miller^{1,3}, and Tony Svejcar^{1,4}

ABSTRACT—Western juniper (*Juniperus occidentalis* spp. *occidentalis* Hook.) expansion in the northern Great Basin has reduced shrubsteppe productivity and diversity. Chainsaw cutting of western juniper woodlands is commonly applied to remove tree interference and restore sagebrush plant communities. Studies assessing understory response following cutting have been limited to early successional stages and have not evaluated the effects of western juniper debris on plant succession. Cutting western juniper produces a large amount of debris which is commonly left on site, occupying a significant portion of treated areas. This study evaluated successional dynamics spanning 13 years after western juniper cutting. Four 0.45-ha blocks were selected on Steens Mountain in southeastern Oregon. Western juniper cover averaged 26% and mature tree density averaged 250 trees · ha⁻¹. Blocks were cut in late summer 1991. Understory standing crop, cover, and density were compared among 3 locations: old canopy litter mats (canopy), interspace, and area underneath cut western juniper (debris). In the interspace, perennial grasses increased in cover and in standing crop relative to other functional groups. In canopy and debris locations, species composition shifted in the 6th year after cutting as annual grass cover, density, and standing crop increased. However, by 2003, perennial grass biomass was 2 times greater than annual grass biomass in canopy and debris locations. Because annual grasses increased in areas of debris accumulation, managers need to be cognizant of western juniper treatments that create safe sites that are favorable to the establishment of weedy species. Retaining western juniper debris on this site did not increase establishment and growth of perennial grasses compared to the interspace. A shift in perennial grass dominance from Thurber's needlegrass (*Achnatherum thurberianum* [Piper] Barkworth) to bottlebrush squirreltail (*Elymus hystrix* [Nutt.] Smith) occurred in areas of debris accumulation. Our results demonstrated that long-term vegetation evaluations are necessary to properly assess management activities and disturbance.

Key words: *Bromus tectorum*, annual grasses, *Juniperus occidentalis*, litter, long-term succession, Thurber's needlegrass, bottlebrush squirreltail.

Western juniper (*Juniperus occidentalis* ssp. *occidentalis* Hook.) woodlands have increased from an estimated 0.4 to 3.5 million hectares over the past 130 years in the northern Great Basin (Miller et al. 2005). There is convincing evidence that western juniper expansion has reduced shrubsteppe productivity, structure, and composition (Vaitkus and Eddleman 1987, Bates et al. 2000, Miller et al. 2000), altered water and nutrient cycles (Buckhouse and Mattison 1980, Josiatis 1990, Bates et al. 2000, 2002, Roberts and Jones 2000, Miller et al. 2005), and decreased wildlife habitat (Miller et al. 1999, 2005, Noson et al. 2006). Thus, control of western juniper has become an increasingly major focus of land management since the early 1960s. The primary methods used to remove western juniper are prescribed fire and mechanical cutting with chainsaws and tractor mounted shears. The speed and composition of

shrub-understory response to western juniper control is dependent on disturbance severity (Bates et al. 2006), climate conditions (Eddleman 2002a, Bates et al. 2005), spatial location (Bates et al. 1998), pretreatment vegetation composition (Young et al. 1985, Bates et al. 2000), and site potential (Eddleman 2002b).

Hand cutting western juniper with chainsaws produces a large amount of debris, which is commonly left on site. The effects of debris on successional dynamics have only been investigated in short-term studies (Young et al. 1985, Bates et al. 1998). Western juniper debris accumulations alter plant composition (Bates et al. 1998) and may promote establishment of undesirable annual grasses (Young et al. 1985). The response of cheatgrass (*Bromus tectorum* L.) and medusahead (*Taeniatherum caput-medusae* L.) following fire and mechanical treatments is a major concern in pinyon-juniper

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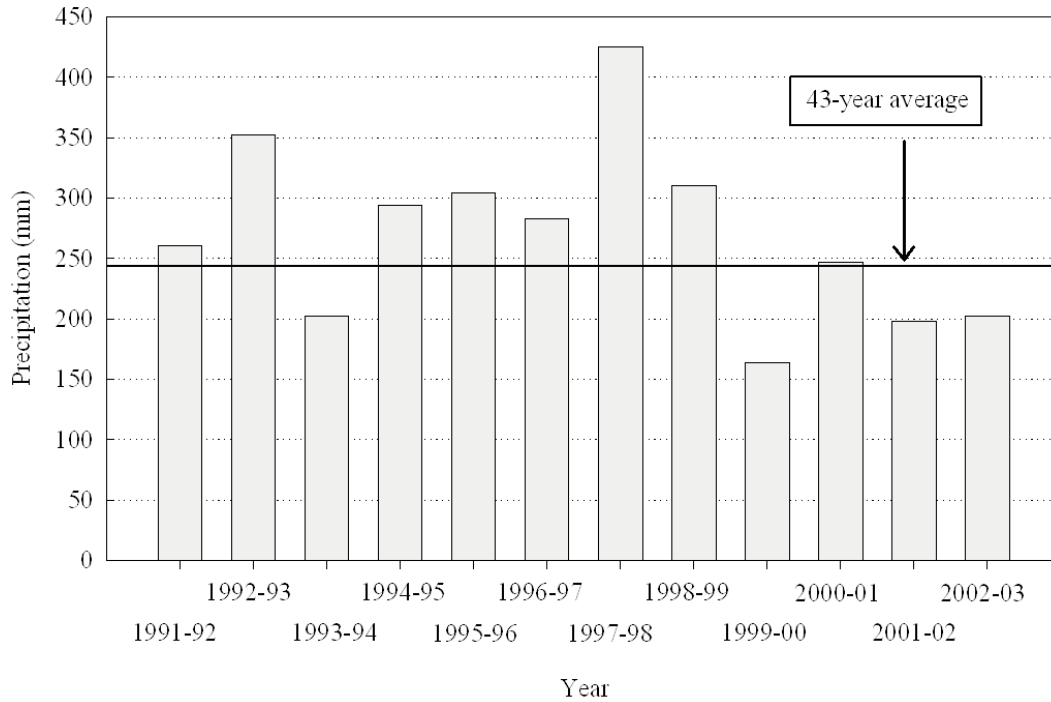


Fig. 1. Annual precipitation (mm) for the years 1991–2003 and the 43-year average at the Malheur National Wildlife Refuge weather station (1250 m), located 29 km northwest of the site.

woodlands (Svejcar 1999). Annual grasses are often present in drier-mesic woodland associations and have the potential to increase quickly following western juniper treatment (Quinsy 1984, Evans and Young 1985, Vaitkus and Eddleman 1987). The use of western juniper debris and slash to provide a favorable environment for perennial grass establishment was proposed by Eddleman (2002a). Eddleman (2002a) reported greater perennial grass establishment under debris than in interspaces in years with average to above-average precipitation.

The purpose of this study was to evaluate the long-term influence of debris and litter accumulations on vegetation dynamics by revisiting a site where short-term (2 years posttreatment) plant succession after western juniper cutting had been previously reported (Bates et al. 1998). Locations evaluated included interspace, western juniper debris, and canopy (litter mats surrounding tree stumps). Bates et al. (1998) reported that following western juniper cutting, cover and density of herbaceous species associated with interspaces were reduced and species characteristic of canopy locations in-

creased under debris. For example, in our earlier study we measured greater establishment of bottlebrush squirreltail (*Elymus hystrix* [Nutt.] Smith) in debris compared to interspaces. Locations were expected to remain floristically distinct in later successional stages. We also suggested that compared to the interspace, debris locations would over time provide more favorable establishment areas for other perennial grass species (Bates et al. 1998). Vegetation in the earlier study was primarily composed of native perennials, and it was hypothesized that (1) the annual stage of succession had been bypassed and (2) plant succession would be dominated by perennial grasses and forbs. It was also anticipated that herbaceous cover and density would increase above early successional levels following cutting because all locations remained open to further recruitment and colonization (Bates et al. 1998).

METHODS

The present study was conducted between 1991 and 2003. Data from 1991 to 1993 published in Bates et al. (1998) addressed the

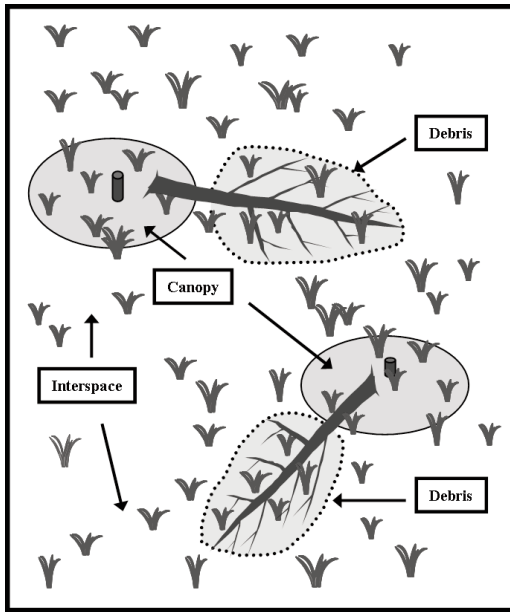


Fig. 2. Location delineations (canopy, debris, and interspace) for the cut juniper treatment. The canopy locations are the litter mats beneath pre-cut western juniper trees. The debris locations are former interspaces that were covered by trees after cutting. Interspaces are open areas between canopy and debris locations.

effects of location on early plant successional dynamics. Here we compare early successional data from 1992–1993 with data collected in 1997 and 2003 to assess long-term effects of western juniper cutting on successional dynamics. Because location measurements require a considerable amount of time, we decided to space these measurements about 5 years apart. In this study there were 4- and 6-year measurement intervals, which coincided with major changes in plant composition. Observed changes were a factor in selecting these measurement years.

The study site was on Steens Mountain in southeastern Oregon (118°36'E, 42°55'N). Elevation at the site was 1575 m and aspect was west facing. The site was dominated by 80-year-old western juniper woodland. Western juniper had fully occupied this site as indicated by limited lateral and terminal leader growth, crown lift, and lack of further juniper recruitment. Western juniper canopy cover averaged 26.5% and tree density averaged 250 trees · ha⁻¹. Sagebrush was eliminated from the site by western juniper interference, though previ-

ous shrub occupancy was evidenced by the presence of numerous shrub skeletons. The dominant shrub was basin big sagebrush (*Artemisia tridentata* spp. *tridentata* [Beetle & Young] Welsh). Herbaceous cover averaged 5.5%. Bare ground and rock in the interspace was about 95%. Understory composition was a mix of native grasses and nonnative forbs with Sandberg's bluegrass (*Poa secunda* J. Presl) and pale alyssum (*Alyssum alyssoides* L.) being the most common species. Other species characterizing the site were bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey), bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve), Thurber's needlegrass (*Achnatherum thurberianum* [Piper] Barkworth), and basalt milkvetch (*Astragalus filipes* Torr.). Cheatgrass (*Bromus tectorum* L.) was present across the site (<1% cover) and primarily grew beneath juniper canopies. The majority of the annual precipitation at this site falls between November and late May. Precipitation (1 Oct–30 Sep) at the Malheur National Wildlife Refuge weather station located 30 km northwest (1250 m) of the site has averaged 248 mm annually for the past 43 years (Fig. 1). Soils are mainly Typic Vitrixerands and Typic Calcixerolls and are underlain by a welded volcanic ash tuff, which restricts root penetration at 40 cm.

Four 0.45-ha blocks were established in June 1991. (In the earlier study [Bates et al. 1998] there were eight 0.9-ha blocks. After 1993, four blocks were put back into pasture and were grazed. The 4 blocks used in the present study were fenced and have not been grazed.) All western juniper >20 cm were cut down using chainsaws in August 1991. Felled trees were left in place. Herbaceous sampling was spatially stratified by location: canopy, interspace, and debris (Fig. 2; in Bates et al. [1998], canopy was referred to as duff and debris was referred to as slash). Canopy locations were the litter mats beneath pre-cut western juniper trees, and they occupied about 25% of the treatment area. Interspaces were sampled about 3 m from the outer edge of the canopy or debris locations. Debris locations were former interspace areas that were covered by trees after cutting, and they occupied about 20% of the area. Prior to cutting, debris locations were identical to the interspace in species composition and cover. Herbaceous canopy cover and density of understory species were measured inside 0.2-m² frames in 1991, 1992, 1993, 1997,

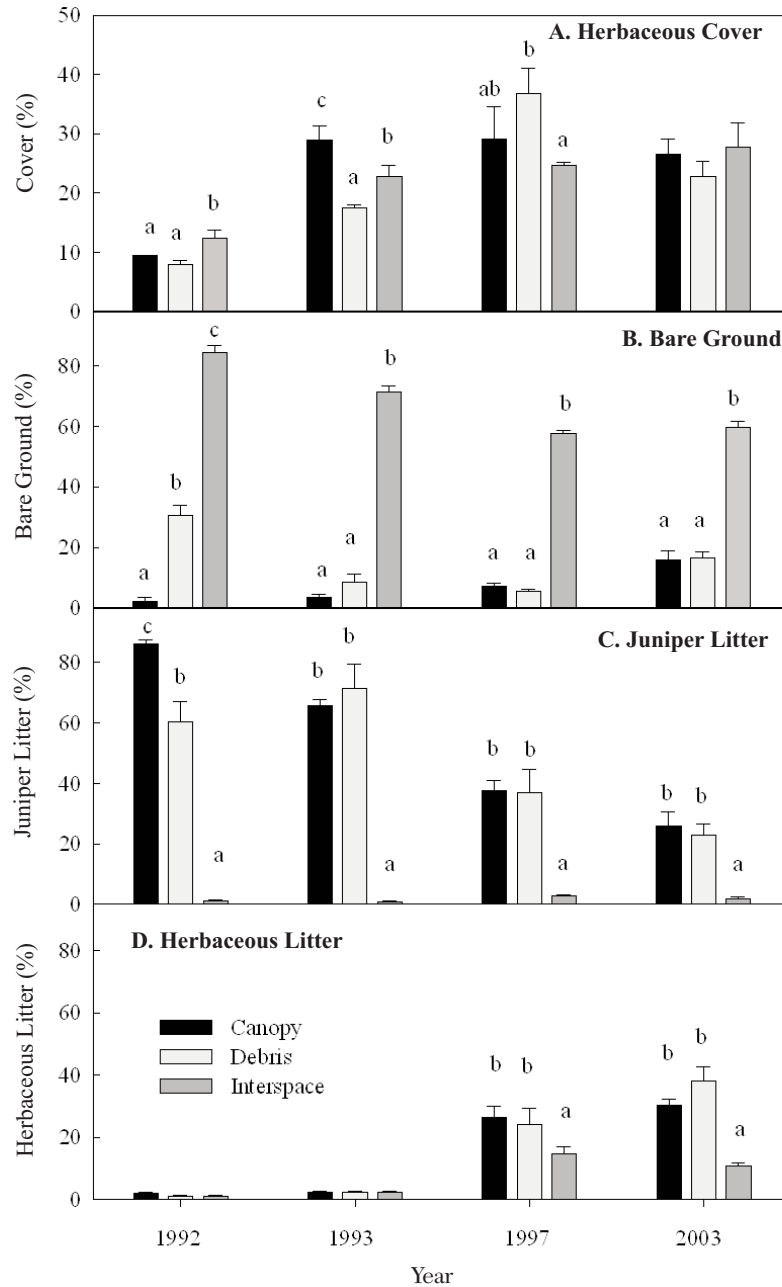


Fig. 3. Ground cover (%) response variables for canopy, debris, and interspace locations. Error bars represent $1 s_{\bar{x}}$. Significant differences ($P < 0.05$) among locations, by year, are indicated by different lower case letters.

and 2003. Canopy locations were measured in the 4 cardinal directions around 12 randomly selected stumps in each treatment plot. For the canopy locations, frames were placed on the outer edge of the litter mat, with the long edge of the frame facing the stump. For

the debris locations, frames were randomly placed under 12 cut juniper trees (4 frames per tree).

The study was expanded in June 1997 and 2003 by sampling for herbaceous biomass. Standing crop was sampled by location in

TABLE 1. *P*-values for cover, density, and biomass comparing location in cut juniper woodlands, Steens Mountain, Oregon. Asterisks (*) indicate significant main effects and year \times location interactions at $P < 0.05$. Dashes indicate data not collected for these response variables.

Response variable	Cover			Density			Biomass		
	Year	Location	Year \times location	Year	Location	Year \times location	Year	Location	Year \times location
Ground cover									
Total herbaceous	0.0064*	0.4861	0.0237*	—	—	—	0.0024*	0.0001*	0.0002*
Bareground/rock	0.0017*	0.0012*	0.0017*	—	—	—	—	—	—
Juniper litter	0.0001*	0.0008*	0.0001*	—	—	—	—	—	—
Herbaceous litter	0.0001*	0.0001*	0.0001*	—	—	—	—	—	—
Moss/crust	0.0002*	0.8529	0.3461	—	—	—	—	—	—
Functional group									
Sandberg's bluegrass	0.0001*	0.1804*	0.0001*	0.0035*	0.0231*	0.0032*	0.1648	0.0016*	0.0333*
Perennial grass	0.0001*	0.0026*	0.5366	0.0041*	0.6937	0.7762	0.0091*	0.0211*	0.0083*
Annual grass	0.0001*	0.0012*	0.0003*	0.0001*	0.0001*	0.0001*	0.0001*	0.0002*	0.0025*
Perennial forb	0.0463*	0.4724	0.5618	0.7274	0.0018*	0.3546	0.0008*	0.0022*	0.0028*
Annual forb	0.0001*	0.0029*	0.0077*	0.0001*	0.0021*	0.0017*	0.1096	0.0002*	0.0970
Species									
Bluebunch wheatgrass	0.0018*	0.2374	0.8545	0.0321*	0.9230	0.8086	—	—	—
Squirreltail	0.0041*	0.0006*	0.6174	0.0001*	0.0001*	0.0457*	—	—	—
Thurber's needlegrass	0.4097	0.0001*	0.5033	0.0103*	0.0001*	0.2314	—	—	—
Other perennial grass	0.3650	0.0169*	0.6675	0.0306*	0.2014	0.4050	—	—	—
Pale agoseris	0.2621	0.3388	0.8646	0.3154	0.1193	0.6374	—	—	—
Basalt milkvetch	0.0014*	0.4276	0.5852	0.0188*	0.0015*	0.1888	—	—	—
Mariposa lily	0.0084*	0.1522	0.4043	0.0717	0.0015*	0.2589	—	—	—
Western hawkbeard	0.0016*	0.0485*	0.5342	0.0881	0.0463*	0.7621	—	—	—
Tailcup lupine	0.7048	0.0090*	0.3440	0.9797	0.0392*	0.1727	—	—	—
Hoary aster	0.0001*	0.0126*	0.0034*	0.0291*	0.3191	0.4004	—	—	—
Other perennial forbs	0.0025*	0.5467	0.2461	0.8937	0.4650	0.1974	—	—	—
Pale alyssum	0.0010*	0.0289*	0.2194	0.0001*	0.0001*	0.0001*	—	—	—
Epilobium	0.0522	0.1874	0.1436	0.0494*	0.0030*	0.0617	—	—	—
Tansy mustard	0.0001*	0.0001*	0.0001*	0.0125*	0.0354*	0.0458*	—	—	—
Prickly lettuce	0.0001*	0.0574	0.1274	0.0001*	0.0426*	0.0530	—	—	—
Microseris	0.0001*	0.1628	0.4871	0.0002*	0.0001*	0.0001*	—	—	—
Yellow salsify	0.0015*	0.7346	0.6107	0.0005*	0.3085	0.3289	—	—	—
Other annual forbs	0.0001*	0.4580	0.0796	0.0003*	0.0001*	0.0023*	—	—	—

each plot using twenty-five 1-m² frames. Herbage was clipped by functional group to a 2.5-cm stubble height and then dried to a constant weight at 48°C. Functional groups were Sandberg's bluegrass, perennial bunchgrasses (e.g., Thurber's needlegrass, bluebunch wheatgrass, bottlebrush squirreltail), perennial forbs, annual grasses (cheatgrass and Japanese brome [*Bromus japonicus* L.]), and annual forbs.

The experimental design was a randomized block with 4 blocks and 3 locations. Blocking removed the differences associated with soils described for the site and increased the precision of the results. Analysis of covariance was used to determine the effects associated with block, year, and location on cover and density of functional groups and species. Data from 1991

were used as a baseline covariate. Analysis of variance was used to test for location effect by year to assist in explaining interactions in herbage cover and density. All statistical analyses were performed using the Statistical Analysis System (SAS Institute, Inc. 2002). Arcsine square-root transformations on cover and density data were used to meet assumptions of normality and homogeneity of variance for ANCOVA and ANOVA. Nontransformed means are reported from statistical comparisons of the transformed means. Herbaceous standing crop (functional group and total herbaceous) was analyzed in a repeated measure ANOVA. The model included block (4 blocks, $df = 3$), year (1997 and 2003, $df = 1$), location (canopy, debris, and interspace, $df = 2$), and year \times location interaction ($df = 2$, with the error term $df = 15$). For all statistical tests, $\alpha = 0.05$.

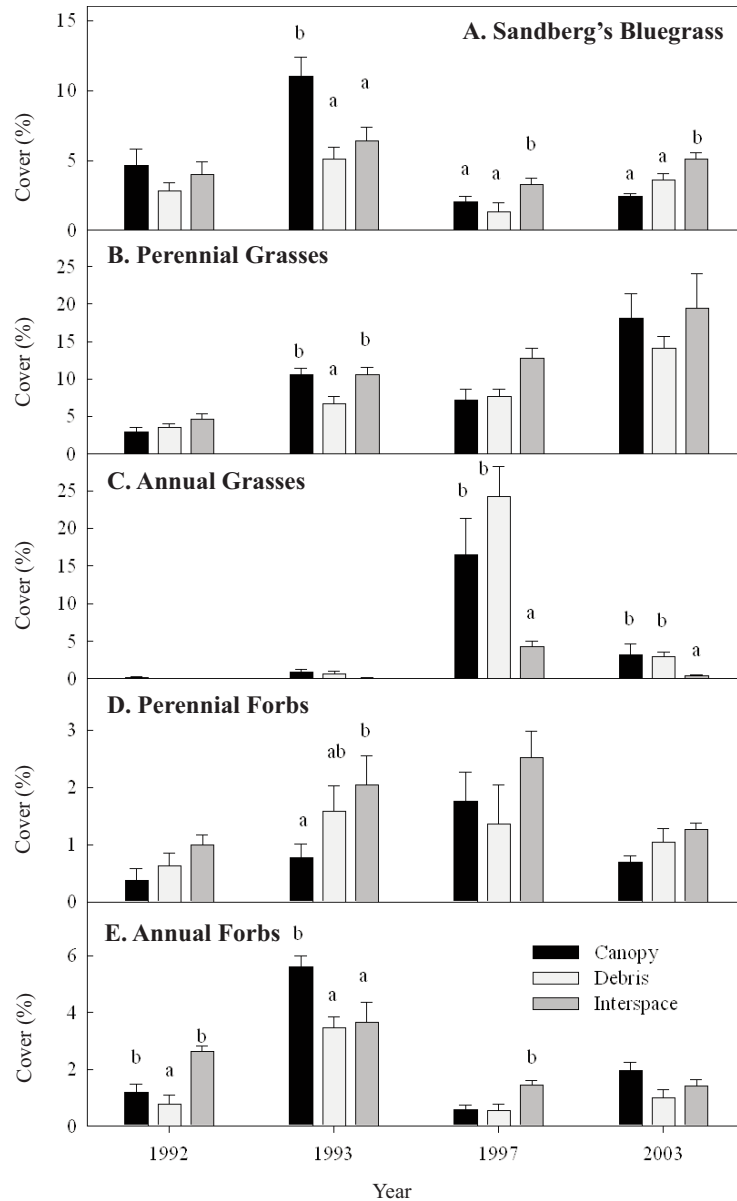


Fig. 4. Functional group cover (%) among the 3 locations for Sandberg's bluegrass (A), perennial grasses (B), annual grasses (C), perennial forbs (D), and annual forbs (E). Error bars represent 1 s_e . Significant differences ($P < 0.05$) among locations, by year, are indicated by different lower case letters.

Interactions were separated using Fisher's protected LSD.

RESULTS

Ground Cover

Ground cover was different among locations across the sampling period. Year and location

interactions were significant for all ground cover response variables (Table 1, Fig. 3). Herbaceous canopy cover increased in all locations between 1992 and 1997 and differed among locations (Fig. 3A). By 2003 herbaceous cover did not differ among the locations. Bare ground declined in interspace and debris locations across years because of increased cover of

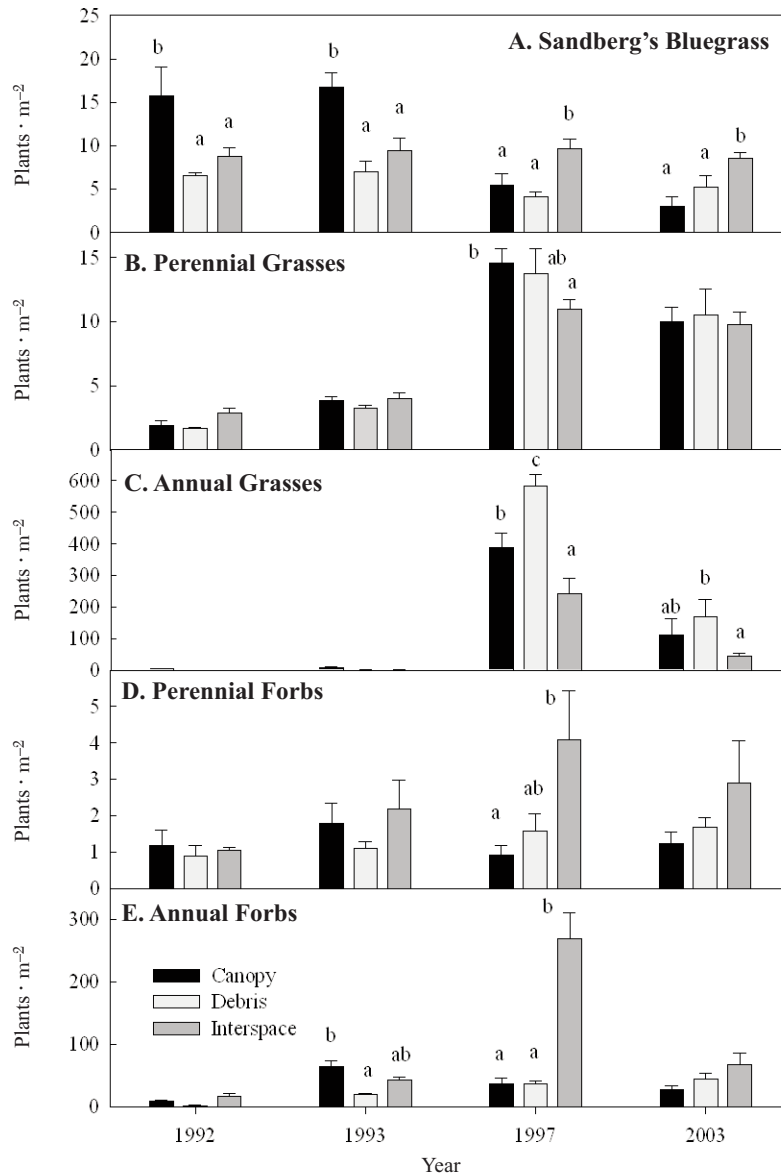


Fig. 5. Functional group densities (plants · m⁻²) among the 3 locations for Sandberg's bluegrass (A), perennial grasses (B), annual grasses (C), perennial forbs (D), and annual forbs (E). Error bars represent 1 s.e. Significant differences ($P < 0.05$) among locations, by year, are indicated by different lower case letters.

herbaceous plants and litter (Fig. 3B–D). In all years, bare ground remained greater in the interspace than in the other locations. Litter cover was highly dynamic, particularly in debris and canopy. In debris and canopy locations, juniper litter was the dominant ground cover in 1992, 1993, and 1997 (Fig. 3C). Herbaceous litter increased in both locations and by 2003 was greater than juniper litter cover (Fig. 3D).

Herbaceous litter in the interspace increased between 1992 and 2003, but remained less than in debris and canopy locations.

Functional Group Cover, Density, and Biomass

Functional group measurements were useful in detecting major plant compositional changes. Year and location interactions were significant

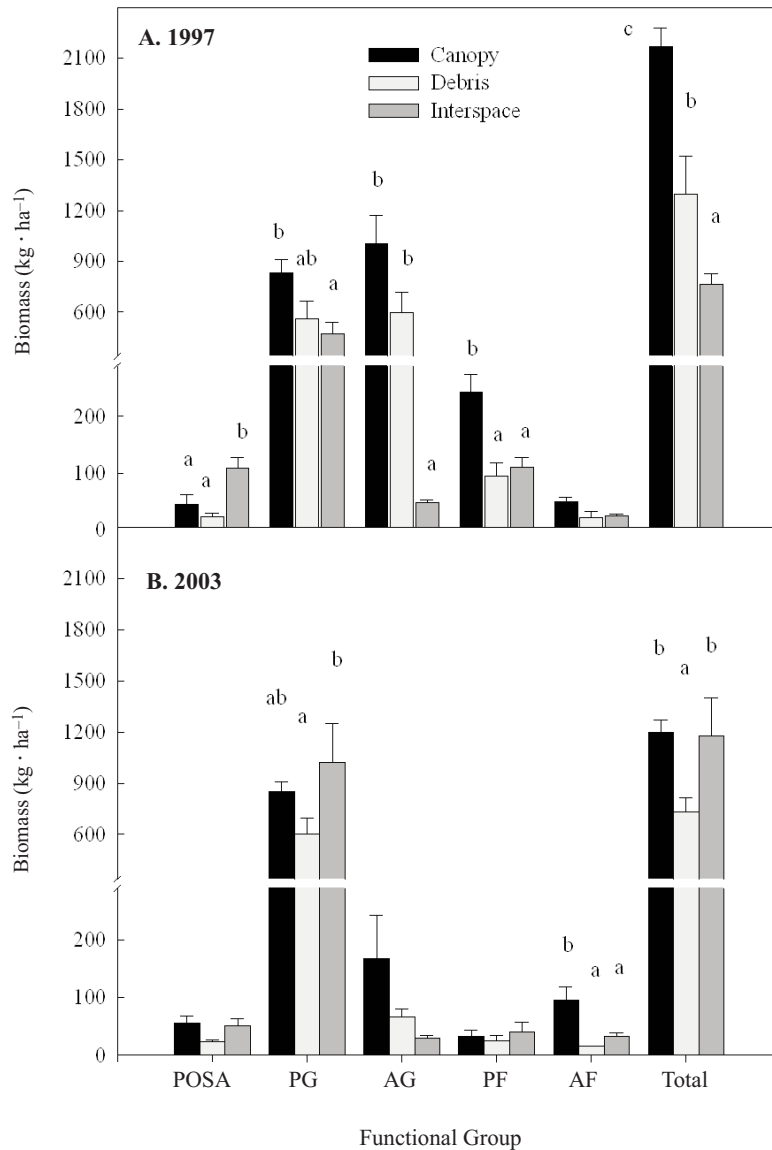


Fig. 6. Biomass ($\text{kg} \cdot \text{ha}^{-1}$) of the functional group biomass in 1997 (A) and 2003 (B). Error bars represent $1 s_{\bar{x}}$. Significant differences ($P < 0.05$) among locations for the functional groups, by year, are indicated by different lower case letters. Functional groups are Sandberg's bluegrass (POSA), perennial grasses (PG), annual grasses (AG), perennial forbs (PF), and annual forbs (AF).

for cover and density of Sandberg's bluegrass, annual grasses, and annual forbs (Table 1). In 1993 Sandberg's bluegrass cover comprised the major portion of total herbaceous cover among the locations, particularly in the canopy locations (Fig. 4A). However, by 1997 Sandberg's bluegrass cover declined in all 3 locations (Table 1) and comprised only a small proportion of total herbaceous cover in 1997 and 2003.

Perennial grass cover increased in all locations (Table 1) and made up the highest proportion of herbaceous cover by 2003 (Fig. 4B). Annual grass cover also increased in all locations between 1992 and 1997. In canopy and debris locations, annual grass contributed the largest proportion to total herbaceous cover in 1997 (Fig. 4C). Between 1997 and 2003 there was a large decline in annual grass cover in

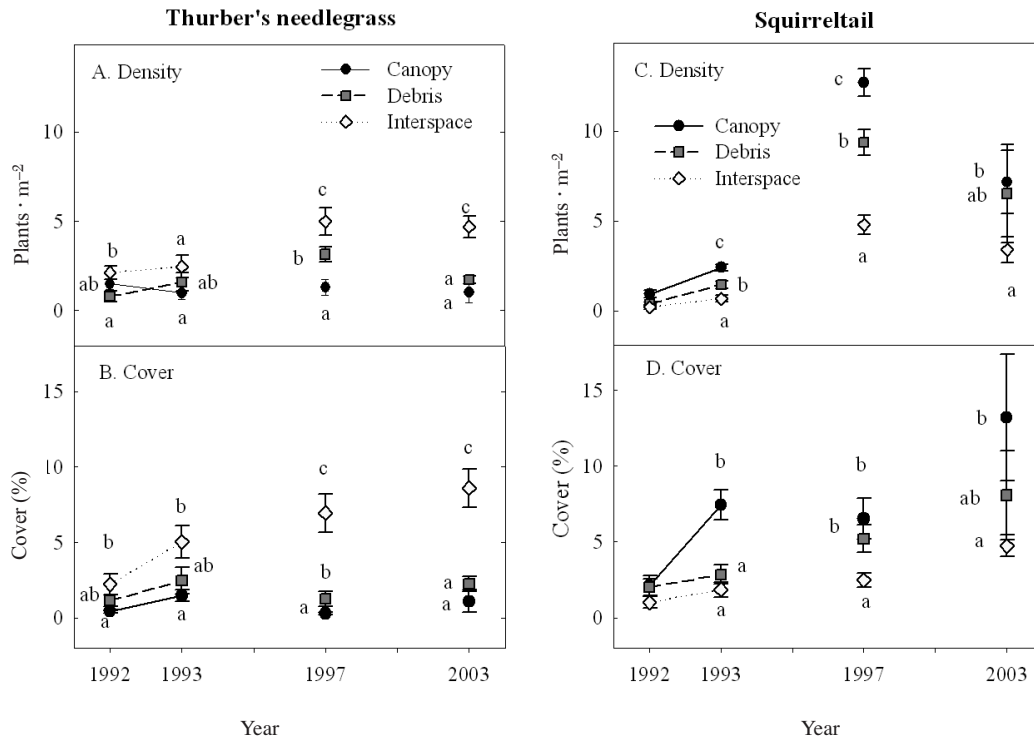


Fig. 7. Thurber's needlegrass density (A) and cover (B), and bottlebrush squirreltail density (C) and cover (D). Error bars represent $1 s_{\bar{x}}$. Significant differences ($P < 0.05$) among locations, by year, are indicated by different lower case letters.

canopy and debris locations. Differences among locations for perennial and annual forb cover were detectable during early succession (1993), but by later stages these differences had largely disappeared (Table 1, Fig. 4D–E).

Density response variables had spatial relationships and trends similar to those measured for functional group covers (Table 1). After increasing nearly 3-fold between 1992 and 1993, Sandberg's bluegrass density decreased between 1993 and 1997 in canopy locations (Fig. 5A). Sandberg's bluegrass density did not change over time in the interspace, and in the last 2 measurement periods, bluegrass density in the interspace was greater than in the canopy and debris locations. Perennial grass and annual grass density increased in all locations between 1993 and 1997 (Fig. 5B–C). Annual grass density was greatest in debris locations, followed in descending order by canopy and interspace locations. Annual grass decreased in all locations in 2003, though densities tended to remain lower in the interspace compared to the other locations. Although perennial forb density

showed a strong location effect (Table 1), location differences were only expressed in 1 year (1997) of the study (Fig. 5D). In early succession, differences among the locations for annual forb density were small and not consistent (Fig. 5E). The densities of annual forbs in the last 2 measurement years were greater in interspace locations than in canopy and debris locations.

In 1997 total biomass in the canopy locations was nearly 3 times greater than in the interspace and over 50% greater than in the debris locations (Fig. 6A). However, total biomass declined in canopy and debris locations between 1997 and 2003, primarily as a result of reduced annual grass and perennial forb production (Fig. 6A–B). In 1997 annual grass represented nearly 50% of total biomass in debris and canopy locations. By 2003 annual grass biomass represented only 6% and 14% of total herbaceous biomass in debris and canopy locations, respectively. As a result of these changes, herbaceous biomass was lower in the debris than in the canopy and interspace locations in 2003.

Perennial grass biomass remained unchanged in canopy and debris locations, but nearly doubled in the interspace between 1997 and 2003. Sandberg's bluegrass and forb biomass were either stable or declining in all locations between 1997 and 2003.

Species Response

Although many species exhibited strong location effects during early succession (1992–1993), only a few species maintained consistent differences among locations during the study (Table 1). Bottlebrush squirreltail, Thurber's needlegrass, western hawksbeard (*Crepis occidentalis* Nutt.), tailcup lupine (*Lupinus caudatus* Kell.), and prickly lettuce (*Lactuca serriola* L.) retained strong location preferences in both cover and density (Table 1). Cover and density of Thurber's needlegrass increased in the interspace between 1993 and 2003 and was greater in the interspace than in canopy and debris locations (Fig. 7A–B). Cover and density of bottlebrush squirreltail increased significantly in all locations between 1993 and 1997; however, the greatest increases in bottlebrush squirreltail were in canopy and debris locations (Fig. 7C–D). Western hawksbeard, tailcup lupine, and pale alyssum were mainly found in the interspace, and prickly lettuce primarily grew under western juniper debris. Observationally it appeared that many of the other forb species were spatially distributed. However, because of low mean values or proportionally high variances, location differences did not present themselves statistically in late succession.

DISCUSSION

It was hypothesized that herbaceous production, cover, and density would increase above early successional levels at all site locations. Herbaceous cover and biomass did increase in all locations through the 6th year posttreatment (1997); however, this trend was not maintained later into succession (2003) in canopy and debris locations. Biomass and cover in canopy and debris locations actually decreased between 1997 and 2003. The increase in herbaceous response variables between 1992 and 1997 was attributed, in addition to juniper removal, to greater than average precipitation (Fig. 1). Since 1999, the region has been in drought, which appeared to explain the de-

crease in biomass and cover in canopy and debris locations between 1997 and 2003. Most of this decrease was recorded in the annual grass and perennial forb functional groups because perennial grass standing crop remained unchanged. Productivity of annual grasses and perennial forbs decreased with reduced precipitation in eastern Oregon (Ganskopp and Bedell 1979, Sneva 1982) and Utah (West and Yorks 2002). However, over the same period, herbaceous biomass and cover, primarily perennial grasses, continued to increase in the interspace. Thus, our hypotheses for increased herbaceous cover and biomass were accepted for the interspace locations and rejected for the canopy and debris locations. The differing location responses suggest that other environmental variables (e.g., litter dynamics, soil nutrient availability) may have influenced late-successional location dynamics. For example, decomposition of western juniper leaf litter in midsuccession may have produced a flush of nutrients that augmented the annual grass response in canopy and debris locations by 1997. Evans and Young (1985) reported that it took several years after juniper control for soil nitrogen to increase in litter deposition areas, which stimulated growth of annual grasses.

Plant composition during early succession is largely influenced by pretreatment site floristics and is dominated by native perennial grasses and forbs (Bates et al. 1998). Thus, we forecasted that further colonization and establishment in all locations would be by native perennials. Our prediction was not entirely correct as plant succession followed multiple pathways dependent on location. The interspace conformed to our initial expectations as native perennials, mainly perennial grasses, increased in dominance. In canopy and debris locations, perennial grasses dominated by the 12th year (2003) following cutting, but only after the vegetation passed through a phase where annual grasses were a significant component of understory cover and production. Although herbaceous vegetation was not measured between 1998 and 2002, we observed that annual grasses continued to play a dominant role in the debris and canopy locations until 2003. Our hypothesis that an annual stage of succession had been bypassed was accurate for the interspace locations, but was not supported by results in the canopy and debris locations.

Following mechanical woodland control treatments, the response of annual grasses in our study developed later than responses reported in other studies. Davis and Harper (1990) measured large increases of annual grasses in the first 2 years after the chaining of pinyon-juniper woodlands in Utah. By the 3rd year after treatment, they measured an 85% decline in annuals as perennial grasses increased. Vaitkus and Eddleman (1987) reported large increases of annual grasses in the first 2 years after the cutting of western juniper woodlands in central Oregon. Eddleman (2002b) later reported that annual grass production on this site had declined from $300 \text{ kg} \cdot \text{ha}^{-1}$ two years after treatment to $12 \text{ kg} \cdot \text{ha}^{-1}$ fifteen years after treatment.

Though there were significant quantitative shifts, the assemblage of species in canopy and interspace locations remained similar to the assemblage that existed in those locations prior to the cutting treatment. In debris locations, understory composition shifted from a plant composition characteristic of the interspace to a composition with greater qualitative and quantitative similarity to canopy locations within the first 2 years after cutting (Bates et al. 1998). This compositional shift in the debris locations persisted through 2003, thirteen years after treatment.

Management Considerations

An argument advanced for retaining juniper debris is that perennial grass establishment may be enhanced under cut trees and slash, particularly on more arid sites (Miller et al. 2005). Except for bottlebrush squirreltail, we found that retaining juniper debris on-site did not benefit establishment and growth of perennial grasses when compared to interspace and canopy locations. The density of Thurber's needlegrass and bluebunch wheatgrass remained unchanged in debris locations. However, we did not actually test the effects of debris on perennial grass seed germination and plant establishment. This study relied on natural dispersal mechanisms, and it is possible that seed from grasses such as Thurber's needlegrass and bluebunch wheatgrass did not disperse into canopy and debris locations. Bottlebrush squirreltail seed did collect in debris and canopy locations as a result of wind dispersal (Bates et al. 1998). Bottlebrush squirreltail density under

juniper debris increased 500% by 1997, suggesting that leaving cut trees in place may be beneficial for establishment of perennial grasses when grasses are seeded into these locations. Eddleman (2002b) reported some success with establishment of selected perennial grass species that were directly seeded into debris accumulations, though success was dependent upon the site receiving average to above-average winter (November–January) precipitation.

Presence of annual grasses remains a concern in many western juniper woodlands, as annual grasses have shown the potential to increase rapidly and dominate following juniper control, particularly in areas with mesic soil temperature regimes (Quinsey 1984, Evans and Young 1985). In areas with frigid soil temperature regimes or less arid, more productive communities, invasion by annual grasses is not considered as high a risk after juniper control (Miller et al. 2000, 2005). The plant community in our study is in a transitional location where annual grasses infestation may or may not pose a threat following disturbance. Eliminating annual grasses from these transitional communities is probably not feasible, but our results suggest that designing treatments that alter or take away preferred establishment sites could reduce the potential for increases of annual grasses. Svejcar (2003) and Sheley and Krueger-Mangold (2003) proposed that when managers develop strategies to reduce weed infestations, they must consider site availability, species availability, and species performance. By targeting establishment sites for weeds, it may be possible to direct successional trajectories so that desired outcomes are achieved (Svejcar 2003). In our study, areas of juniper litter accumulation provided favorable sites for establishment and development of annual grasses. An obvious solution to reduce establishment of annual grasses is removal of the juniper debris. Debris removal methods could include additional mechanical treatment (Brockway et al. 2002) and debris burning (Miller et al. 2005). Fire effectively removes western juniper debris, but the seasonality of burning will affect understory response (Bates et al. 2006). Fall burning in areas with dry soils severely impacts herbaceous vegetation, killing perennial bunchgrasses under cut trees and encouraging establishment of invasive biennial and annual forbs (Bates et

al. 2006). Winter or early spring burning of juniper debris has been documented to have little impact on understory composition, thus permitting perennial herbaceous vegetation to increase rapidly after application of these 2 treatments (Bates et al. 2006, Miller et al. 2005).

Conclusions

Our results suggest that managers need to recognize that the cutting of western juniper woodlands, while substantially increasing cover and production of herbaceous species, has the potential to create locations that are favorable to establishment and growth of weedy species. To reduce the likelihood of annual grass development after cutting, areas of litter deposition might be the focus of additional management, as these areas can represent sizable portions of treated areas. Debris and canopy locations comprised 45% of our study area. The results of this study also indicate that patience may be required to permit development of desired changes in plant composition. Because the response of vegetation to disturbance in semiarid systems can develop relatively slowly, proper assessment of vegetation manipulations in plant communities requires a long-term approach. A pretreatment density of 2–3 perennial bunchgrasses \cdot m⁻² appeared to be sufficient to permit natural recovery after western juniper control on this site. Perennial bunchgrass density peaked in the 6th year posttreatment, and the results suggested that 9–12 plants \cdot m⁻² were sufficient to fully occupy the site and dominate herbaceous composition later in succession. If current vegetation trends continue at our study site, annual grasses will likely continue to decline in the community as native perennial grasses increase.

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