Research

Relationships Between Western Juniper (*Juniperus occidentalis*) and Understory Vegetation

D. E. Coultrap, K. O. Fulgham, D. L. Lancaster, J. Gustafson, D. F. Lile, and M. R. George*

Western juniper has been actively invading sagebrush plant communities for about 130 yr. Western juniper canopy cover generally increases as western juniper invades sagebrush steppe communities and succession progresses toward a western juniper woodland. Our goal was to estimate the impact of juniper invasion and canopy increase on understory vegetation structure and productivity on 101 sites in northeastern California. The primary objectives of this study were to: (1) examine the influence of increasing western juniper canopy cover on the composition and productivity of understory vegetation; and (2) assess the effects of western juniper removal on understory vegetation. Sites in early, mid-, and late successional stages and sites on the same soils that had not been invaded were selected. Sites where western juniper had been removed by prescribed fire, mechanical, or chemical methods were compared to adjacent untreated sites. Western juniper canopy cover, understory cover and species composition, productivity, and bare ground were determined at each site during May through July 2005 and 2006. Regression analysis was used to evaluate the relationship between western juniper canopy cover and understory vegetation parameters. Logistic regression was used to detect understory differences between treated (juniper removed) and untreated (juniper not removed) sites. A significant relationship was found between western juniper canopy cover and understory species richness, shrub cover, forb cover, total grass cover, cheatgrass cover, herbaceous productivity, and bare ground. Removal of western juniper increased total grass cover, cheatgrass cover, and productivity, and reduced bare ground. The results of this study support findings by researchers in other states that western juniper influences plant community structure and productivity, and removal of western juniper might reverse these changes in structure, but also might increase opportunities for invasion of cheatgrass.

Nomenclature: Western juniper, *Juniperus occidentalis* var. *occidentalis* Hook.; sagebrush, *Artemisia tridentata* Nutt.; cheatgrass (*Bromus tectorum* L.).

Key words: Succession, species richness, cover, productivity, bare ground.

According to Miller et al. (2005), in the past 130 yr, western juniper has expanded to approximately nine million acres in the northwestern United States (Figure 1). The increased densities and expansion of western juniper have been attributed to fire suppression, historic overgrazing, climate change, and atmospheric CO_2 (Belsky 1996; Miller et al. 2005). Expansion of western juniper threatens to negatively impact water and nutrient cycles, reduce forage production, degrade wildlife habitat, and permanently alter the structure, composition, and diversity of plant communities. Because the influences of western juniper succession on understory vegetation has been the subject of only a few studies (Bunting et al. 1999; Miller et al. 2000), the impacts of western juniper woodland development are not completely known.

Attempts to restore plant communities by removing western juniper have been successful and unsuccessful (Evans and Young 1985; Rose and Eddleman 1994; Vaitkus and Eddleman 1987). Western juniper removal is

DOI: 10.1614/IPSM-07-008.1

* First, third, fifth, and sixth authors: Staff Research Associate, Extension Range and Natural Resources Advisor, Extension Livestock and Natural Resources Advisor and Extension Rangeland Management Specialist, Department of Plant Sciences, University of California, Davis, CA 95616; second author: Department of Forestry and Wildland Resources, Humboldt State University, Arcata, CA 95521; fourth author: Rangeland Specialist, USDA Natural Resources Conservation Service, Davis, CA 95616. Corresponding author's E-mail: mrgeorge@ucdavis.edu

Interpretive Summary

The results of this study apply to 101 study sites spread across a large area in northeastern California. Most previous studies have relied on a limited number of study sites. Taken together, these studies provide strong evidence that the increases in western juniper canopy cover that occur during succession from initial invasion to closed woodland might reduce species richness and diversity; decrease forb, grass and shrub cover; depress productivity; and result in increased bare ground. Removal of western juniper by using chemicals, fire, or mechanical methods might reverse these changes in structure but might also increase opportunities for invasion of cheatgrass and medusahead on some sites. Consequently, control practices must be used with caution and applied to sites with the highest potential to increase perennial herbaceous species and desirable shrub canopy cover.

a disturbance that can make sites susceptible to invasion by exotic annual weeds (Evans and Young 1985; Miller et al. 2005; Vaitkus and Eddleman 1987).

It is often stated that the understory shrub and herbaceous layer declines as western juniper increases in dominance but only a few studies have evaluated this relationship (Miller et al. 2005). The primary objectives of this study were to: (1) examine the influence of increasing western juniper canopy cover on the composition and productivity of understory vegetation; and (2) assess the effects of western juniper removal on understory vegetation. The specific hypotheses were: (1) as western juniper canopy cover increases, species richness, cover, and productivity (biomass) of understory shrubs, grasses, and forbs will decline, and bare ground will increase; and (2) removal of western juniper generally increases species richness, understory plant cover, and productivity of shrubs and herbaceous vegetation, and reduces bare ground.

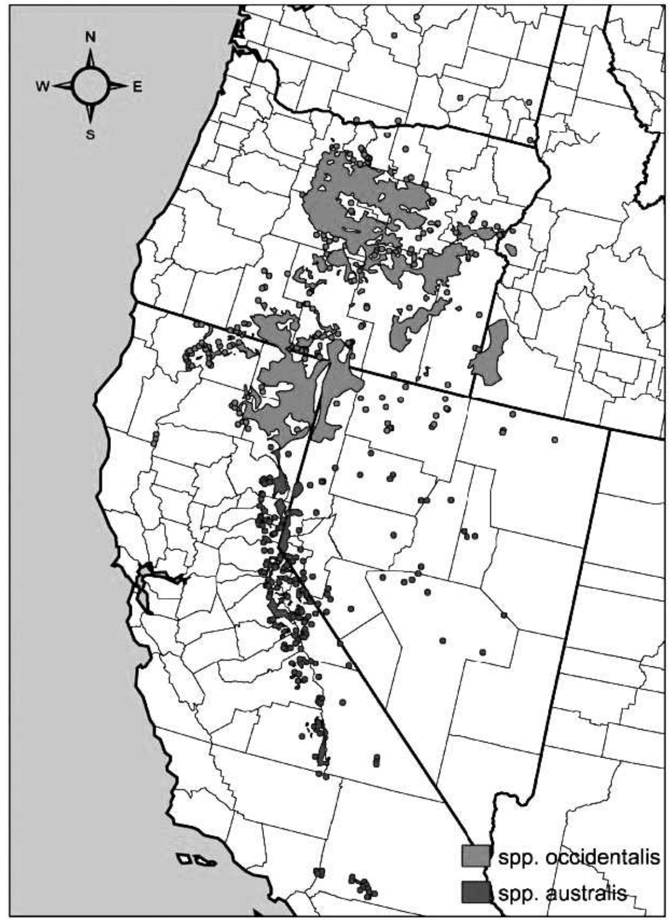

Figure 1. Distribution of western juniper in the Pacific Northwest.

Materials and Methods

Study Area. The study area was located in Modoc, Lassen, and Siskiyou counties in northeastern California (Figure 2). Western juniper woodland and sagebrush steppe rangelands found in these counties lie in the rain shadow of the Sierra Nevada and Southern Cascade Mountains. Western juniper typically occurs in this area between 700 and 2,300 m (3,000 to 7,550 ft) elevation (Hickman 1993). The climate is semiarid and similar to that of the Intermountain Region, with cold winters and dry, hot summers, with most of the precipitation as snow during winter months and rain in spring and fall, although isolated thunderstorms are typical at higher elevations in the summer. Average annual precipitation of the study area is approximately 41 cm (16 in), average minimum temperature is about 0 C (32 F), and the average maximum temperature is about 16 C (61 F).

The soils in this study are highly variable in slope, surface rockiness, depth of the A and B horizon, elevation, and rainfall (Table 1). Most of the soils in this study were loams that varied in rockiness. All were well-drained with slow to moderate permeability and slow to rapid runoff. Runoff typically only occurs during intense thunderstorms. All of the soils are igneous in origin and most are in the Argixeroll great soil group.

Big sagebrush (*Artemisia tridentata* Nutt.) is common in the understory of the study sites. Rubber rabbitbrush [*Chrysothamnus nauseosus* (Pallas ex Pursh) Britt.], green rabbitbrush [*Chrysothamnus viscidiflorus* (Hook.) Nutt.], bitterbrush (*Purshia tridentata* Pursh.), and wax currant (*Ribes cereum* Dougl.) also occurred on some sites. Low sage (*Artemisia arbuscula* Nutt.), snowberry (*Symphoricarpos albus* Blake), and serviceberry (*Amelanchier alnifolia* Nutt.) were found on several sites at higher elevations. The most frequent grass species encountered were Sandberg's bluegrass (*Poa secunda* Vasey), squirreltail (*Elymus elymoides* Swezey), Thurber's needlegrass (*Achnatherum thurberiana* Barkworth), Lemmon's needlegrass (*Achnatherum lemmonii*

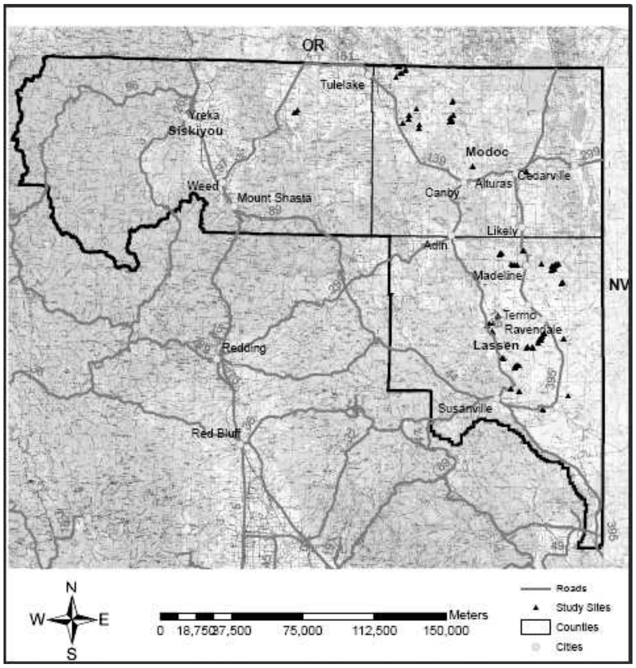

Figure 2. Map of study area in Modoc, Lassen, and Siskiyou counties in northeastern California.

Barkworth), and Idaho Fescue (*Festuca idahoensis* Elmer). Cheatgrass was also present throughout the study area. Study sites were also occupied by a variety of perennial and annual forbs including buckwheat (*Eriogonum* spp. Michx.), fireweed (*Epilobium* spp. L.), lupine (*Lupinus* spp. L.), blue-eyed Mary (*Collinsia* spp. Nutt.), milkvetch (*Astragalus* spp. L.), pepperweed (*Lepidium* spp. L.), and slender phlox (*Microsteris gracilis* Greene).

Field Plots. Plots were selected and surveyed in May, June, and July of 2005 and 2006. The criteria used for plot selection were: (1) study sites were located on soil series common throughout northeastern California (Table 1); (2) study sites appeared to be representative of the plant communities associated with each soil series; (3) sites had different amounts of western juniper canopy cover; (4) opportunity to compare adjacent treated (juniper removed) and untreated sites (juniper not removed); and (5) plot locations had not been grazed. Juniper was removed from treated sites by various methods that included cutting with chainsaws or mechanical shears, using fire or chemicals, and in a few cases, combinations of these methods.

Vegetation data were collected on 101 circular field plots that were 45 m (150 ft) in diameter. Two perpendicular 50 m (150 ft) transects within each field plot were used to measure juniper canopy cover, shrub cover, herbaceous plant cover, and percent bare ground using the line-point intercept technique (Herrick et al. 2005). Species richness, defined as the number of species present on each site, was calculated from the line-point data. Ten 0.18 m^2 (1.92 ft^2) plots were clipped to determine herbaceous production by weight. Herbaceous vegetation in each plot was clipped to approximately 1 cm (0.4 in) stubble height and oven-dried at 65 C (149 F) for about 3 d. Herbaceous species biomass was weighed and data were used to calculate herbaceous species composition (kg/ha [lb/ac]) on a relative weight basis. Productivity of up to four shrubs per plot was estimated following the methods of Dean et al. (1981).

Analyses. Multivariate analysis was used to assess which understory variables are related to western juniper canopy cover. Robust regression analysis was used to determine which variables had a significant relationship with western juniper canopy cover. Differences in understory variables between treated and untreated groups were analyzed using logistic regression analysis. All analyses were performed using Number Cruncher Statistical Systems (NCSS) software (Hintze 2004).

Results and Discussion

Western juniper canopy cover across all sites averaged 12% and ranged from 0 to 74%. Total understory cover was highly variable, but averaged about 61%. A significant relationship was found between western juniper canopy cover and species richness, understory cover and herbaceous productivity (Table 2). Removal of western juniper increased total grass cover, cheatgrass cover, and productivity, and reduced bare ground.

Species Richness. Regression analysis detected a significant negative relationship between western juniper canopy cover and species richness (Table 2, Figure 3). This is consistent with findings from other studies in Oregon and northern California where western juniper dominance reduced understory richness and diversity (Bates et al. 2000; Burkhardt and Tisdale 1969; Miller et al. 2000). However, there are other instances where changes in species richness with western juniper succession were not detected (Bunting et al. 1999; Miller et al. 2000). Miller et al. (2000) found that although western juniper dominance reduces understory diversity on some sites, the impacts of western juniper succession on species richness can depend on the plant association involved. Understory species richness and diversity are important because reductions in species can negatively impact ecosystem services (Bates et al. 2000; West 1993).

When western juniper was removed there was no significant change in species richness (Table 3). Bates et al. (2000) found that herbaceous species diversity and richness increased in mountain big sagebrush–Thurber's needlegrass associations following cutting of western juniper. However, the authors noted that posttreatment plant composition was dictated by species composition

Table 1. Properties of study site soils in Modoc, Lassen, and parts of Siskiyou Counties, Northeastern California.

Soil series	Slope (%)	Surface texture	Soil horizon depth A	Soil horizon depth B	Elevation	Precipitation	Taxonomic class
			cm (in)		m (ft)	mm (in)	
Buckbay	5–30	gravelly ashy loam	30 (12)	73 (29)	1,600–1,900 (5250–6235)	300–400 (11.8–15.8)	Fine-loamy, mixed, superactive, mesic Vitrandic Argixerolls
Delma	0–50	heavy loam	33 (13)	45 (18)	1,300–1,600 (4265–5250)	250–400 (9.8–15.8)	Clayey, smectitic, mesic, shallow Aridic Argixerolls
Devada	0–50	very cobbly loam	10 (4)	33 (13)	1,300–2,300 (4265–7545)	250–350 (9.8–13.8)	Clayey, smectitic, mesic Lithic Argixerolls
Deven	0–50	heavy loam	5 (2)	40 (16)	1,050–2,000 (3445–65560)	250–450 (9.8–17.7)	Clayey, smectitic, mesic Lithic Argixerolls
Dotta	0–30	sandy loam	33 (13)	103 (40.5)	600–1,700 (1970–5575)	300–625 (11.8–24.6)	Fine-loamy, mixed, superactive, mesic Pachic Argixerolls
Fiddler	2–50	stony loam	20 (8)	65 (26)	1,200–2,300 (3935–7545)	300–450 (11.8–17.7)	Clayey-skeletal, smectitic, mesic Typic Argixerolls
Ninemile	0–70	extremely cobbly loam	5 (2)	35 (14)	1,600–2,550 (5250–8365)	250–400 (9.8–15.8)	Clayey, smectitic, frigid Lithic Argixerolls
Petescreek	5–50	gravelly loam	25 (10)	68 (27)	1,650–2,400 (5415–7875)	300–400 (11.8–15.8)	Fine-loamy, mixed, superactive, frigid Pachic Ultic Haploxerolls
Searles	0–80	very stony loam	7.5 (3)	63 (25)	600–2,050 (1970–6725)	225–375 (8.9–14.8)	Loamy-skeletal, mixed, superactive, mesic Aridic Argixerolls
Tunnison	0–15	very cobbly clay	2.5 (1)	68 (27)	1,400–1,950 (4595–6400)	225–325 (8.9–12.8)	Very-fine, smectitic, mesic Aridic Haploxererts
Cowiche	0–20	loam	25 (10)	150 (59)	1300–1620 (4265–5315)	250–400 (9.8–15.8)	Fine-loamy, mixed, mesic, Aridic Argixerolls

prior to treatment. Additionally, herbaceous composition changes might not occur until several years after the western juniper canopy is removed. According to Bates et al. (2000) and Miller et al. (2005) the response of species richness and diversity to western juniper removal might be dependent on a number of factors, including site potential, pretreatment site floristics and composition of the seedbed, weather, type of treatment, time since treatment, and posttreatment management.

Understory cover. Shrub cover (Figure 4), forb cover (Figure 5), and total grass cover (Figure 6) decreased significantly with increasing western juniper dominance (Table 2). This is consistent with previous research (Bunting et al. 1999; Miller and Wigand 1994; Vaitkus and Eddleman 1991), which confirm that reductions in shrub and herbaceous plant cover were associated with succession toward closed western juniper woodlands. Miller et al. (2000) reported a decline in mountain big sagebrush cover with increasing western juniper canopy cover, but could not show a significant relationship between western juniper canopy and herbaceous cover in mountain big sagebrush communities. Other authors (Arnold 1964; Tausch et al. 1981; Tausch and West 1995) reported that herbaceous vegetation decreased as a result of increasing tree canopy cover in other types of juniper woodlands. However, Miller et al. (2005) noted that few studies have evaluated the relationship between western juniper and herbaceous cover.

When western juniper was removed, total grass cover increased significantly but forb and shrub cover did not change significantly (Table 3). Although Bates et al. (1998, 2000) and Rose and Eddleman (1994) documented dramatic increases in plant cover and diversity following removal of western juniper, Bates et al. (2005) found no differences in total plant cover on cut vs. woodland plots, but they did find that plant cover and litter were more evenly distributed on sites where juniper had been cut.

Cheatgrass Cover. The trend for cheatgrass cover was slightly downward as western juniper increased (Figure 7), but this trend was not significant at $P < 0.05$ (Table 2).

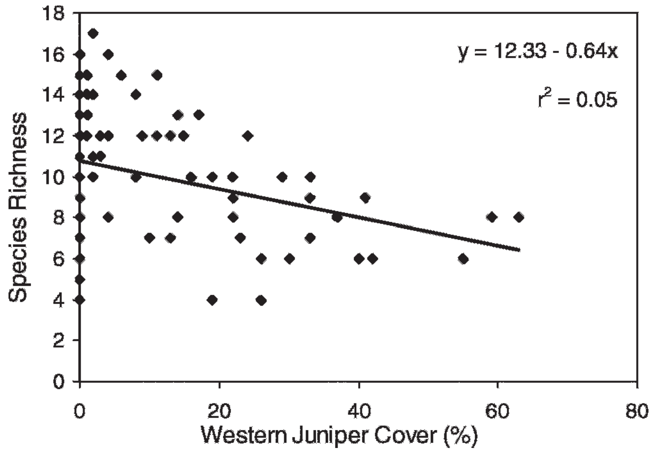

Figure 3. The relationship between and western juniper canopy cover and species richness.

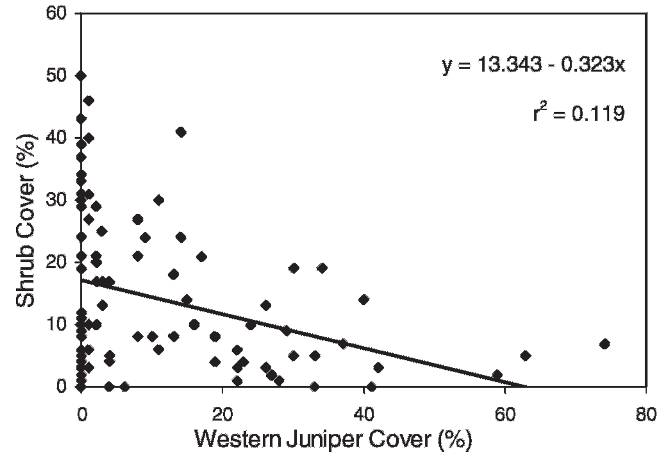

Figure 4. The relationship between western juniper canopy cover and shrub cover.

However at $P < 0.1$, this relationship is significant, suggesting that cheatgrass increases might be expected with increasing western juniper dominance. Cheatgrass cover and total grass cover were higher on treated sites (juniper removed) than on untreated sites, but grass cover (excluding cheatgrass) decreased. This suggests that most of the grass cover increase was due to increased cheatgrass (Table 3). Other studies have found that western juniper control was followed by increased cover of invasive annual grasses such as medusahead [*Taeniatherum caput-medusae* (L.) Nevski] and cheatgrass (Evans and Young et al. 1985; Vaitkus and Eddleman 1987). Bates et al. (2005) found that cheatgrass became more prevalent and had supplanted Sandberg's bluegrass by the fifth year after western juniper removal. These results suggest that managers need to be careful about western juniper management. Research is needed to clarify the relationships between invasive species and juniper removal so that managers can predict the potential for invasion during vegetation management planning.

Site Productivity. Herbaceous productivity decreased significantly with increasing western juniper canopy cover (Figure 8). Although a similar pattern was observed with shrub productivity, the relationship between sagebrush production and western juniper canopy cover was not significant (Table 2). Numerous studies report that succession toward western juniper dominated communities causes reductions in understory productivity (Burkhardt and Tisdale 1976; Evans and Young 1985; Miller and Wigand 1994; Vaitkus and Eddleman 1987, 1991). Western juniper trees have shallow lateral roots that extend to areas well beyond the edge of the tree canopy, which enable them to compete with shrubs and herbaceous vegetation for nutrients and moisture in the interspaces (Tiedemann and Klemmedson 1995; Young et al. 1985). In addition, allelopathic compounds produced by juniper trees might inhibit growth of understory plants (Horman and Anderson 2003). Pieper (1990) discovered that pinyon–juniper canopy cover and total herbaceous biomass had a highly significant inverse relationship.

Table 2. Mean, SD, and SE for understory variables and probability ($P < 0.05$) that the relationship between the variables and western juniper canopy cover are significant.

Variable	Mean	S.D.	S.E.	P
Species richness	10.50	3.47	0.35	0.037
Shrub cover (%)	14.35	12.63	1.29	0.001
Forb cover (%)	10.06	7.48	0.76	0.002
Total grass cover (%)	36.19	20.74	2.12	0.004
Cheatgrass cover (%)	10.14	14.24	1.45	0.066
Grass cover excluding cheatgrass (%)	26.18	16.00	1.63	0.025
Herbaceous production (kg/ha [lb/ac])	371.35 (331.31)	307.07 (273.96)	31.34 (27.96)	0.001
Sagebrush production (kg/ha [lb/ac])	1,426.25 (1272.47)	1,139.77 (1016.88)	116.33 (103.79)	0.879
Bare ground (%)	20.14	10.61	1.08	0.087

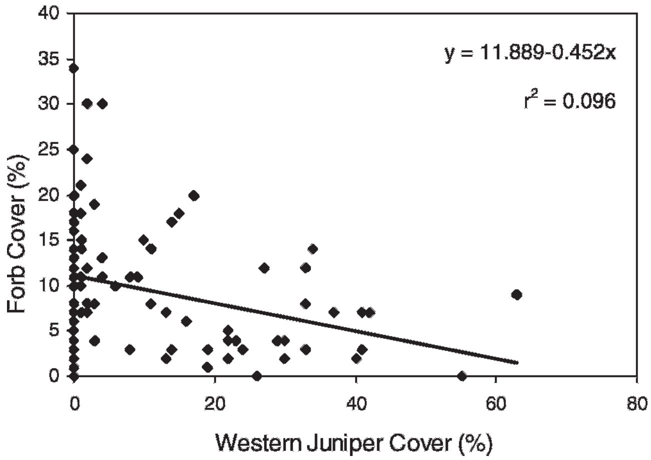

Figure 5. The relationship between western juniper canopy cover and forb cover.

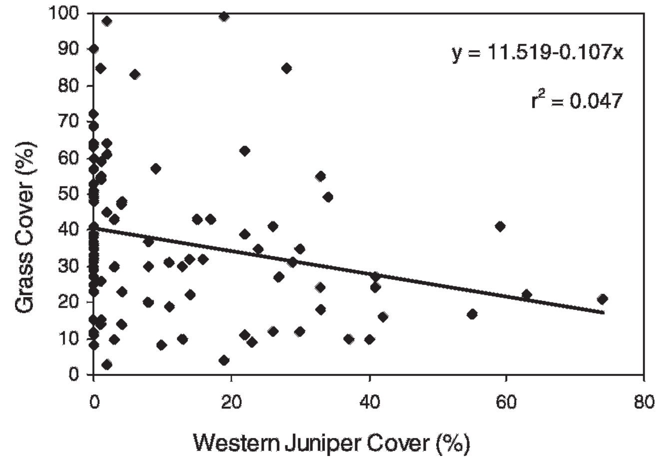

Figure 6. The relationship between western juniper canopy cover and grass cover.

Herbaceous productivity was significantly higher on sites where western juniper was removed (Table 3). Mean sagebrush production was nearly 500 kg/ha (446 lb/ac) lower on treated sites than on untreated sites, and this difference was weakly significant at $P < 0.1$. In many cases, the primary goal of western juniper treatment was to increase site productivity, especially desirable forage and browse species. Several studies report that control of western juniper resulted in significant increases in total understory biomass (Bates et al. 2000; Rose and Eddleman 1994; Vaitkus and Eddleman 1991; Young et al. 1985). However, an increase in total understory biomass doesn't always indicate improvements to the quantity and quality of desirable forage and browse species. Vaitkus and Eddleman (1987) found that although herbaceous production increased significantly after removal of western juniper, much of it was due to increased productivity of annual forbs.

The scientific community and natural resource managers are increasingly concerned about declining populations of avian species that inhabit sagebrush steppe ecosystems. Populations of the greater sage grouse (*Centrocercus urophasianus*) have been declining dramatically in recent decades (Braun 1998; Connelly and Braun 1997). The greater sage grouse typically occupy open sagebrush plains; nesting under sagebrush plants; eating sagebrush, forbs, and insects; and using sagebrush and grass for cover. Therefore, if western juniper invasion into sagebrush steppe negatively impacts the understory, it could degrade sage grouse habitat and negatively impact sage grouse populations. If western juniper removal improves understory productivity it could prove useful for restoring sage grouse habitat.

Bare Ground. The relationship between bare ground in interspaces and western juniper dominance is of great importance, because, as reported by Bates et al. (2000),

Table 3. Comparison of western juniper removal effects on species richness, cover, production, and bare ground using logistic regression.

Variable	Mean treated group ($n = 27$)	Mean untreated group ($n = 67$)	P
Species richness	10.2	10.6	0.621
Shrub cover (%)	12.2	15.2	0.295
Forb cover (%)	11.8	9.3	0.135
Total grass cover (%)	47.4	31.1	0.002
Cheatgrass cover (%)	17.6	11.9	0.003
Grass cover excluding cheatgrass (%)	29.7	24.6	0.017
Herbaceous production (kg/ha [lb/ac])	651.7 (581.4)	274.8 (245.2)	0.000
Sagebrush production (kg/ha [lb/ac])	1,075.5 (959.5)	1,549.5 (1382.4)	0.060
Bare ground (%)	16.7	21.6	0.049

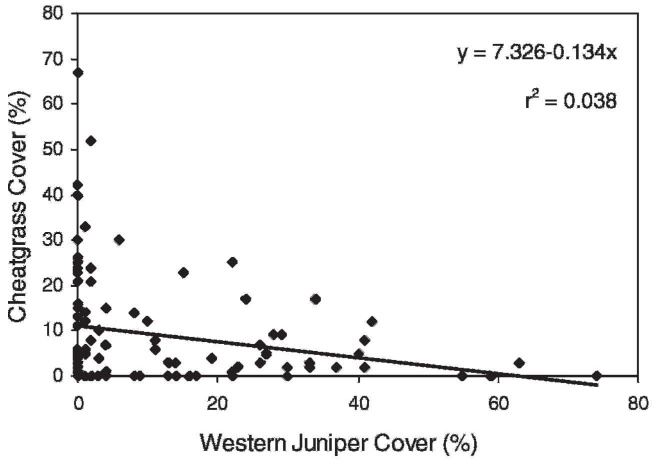

Figure 7. The relationship between western juniper canopy cover and cheatgrass cover.

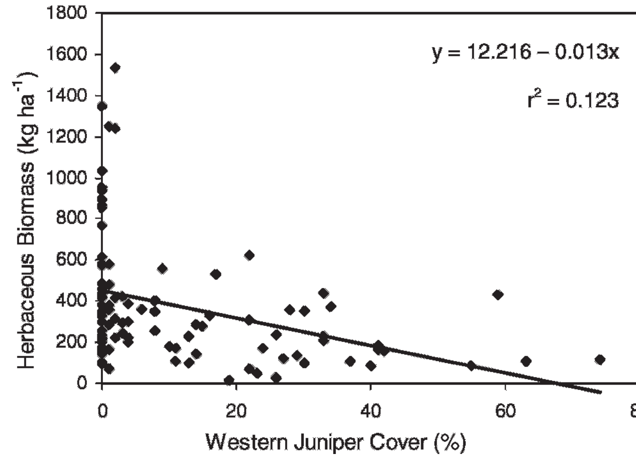

Figure 8. The relationship between western juniper canopy cover and herbaceous biomass.

erosion rates are highest in the interspace zones of semiarid ecosystems (Wilcox and Breshears 1994). Studies in Oregon have shown that sedimentation rates were higher and infiltration rates lower on western juniper sites when compared to other ecosystems in eastern Oregon (Buckhouse and Gaither 1982). Additionally it was shown that infiltration rate decreased as bare ground increased (Gaither and Buckhouse 1983).

Bare ground is used as an indicator of rangeland health. Rangeland health is defined as "the degree to which the integrity of the soil, vegetation, water, and air, as well as the ecological processes of the rangeland ecosystem, are balanced and sustained" (SRM 1999). Soil/site stability, hydrologic function, and integrity of the biotic community are the three interrelated attributes of rangeland ecosystems used to assess rangeland health (Pellant et al. 2005). The relative amount of bare ground on a site greatly affects soil/site stability and hydrologic function, and therefore provides an indication of the health of a western juniper rangeland ecosystem.

Findings from a study in Oregon and California suggested that there are no differences in percent bare ground in the interspaces between western juniper woodlands in the early stages of development and closed woodlands in the same study area (Miller et al. 2000). However, this same study showed that bare ground in the interspaces increased with increasing western juniper dominance in the Mountain big sagebrush–Thurber's needlegrass alliance. Another study from central Oregon found that higher amount of bare ground was related to presence of western juniper (Roberts and Jones 2000). However, there was no significant relationship between western juniper canopy cover and percent bare ground in this study. This could be an artifact of the way that bare ground was measured. Miller et al. (2000) estimated bare ground in 0.20 m^2 (2.15 ft^2) plots placed at increments along transects within study sites. Bates et al. (2000) separated plots into interspace and duff zones, and then estimated ground cover provided by trees, litter zones, and canopy cover of herbaceous plants along transects. Roberts and Jones (2000) simply separated plots into two categories based on the presence or absence of western juniper, and used a point-intersection method for measuring vegetative cover and bare ground. In this study, bare ground was measured by line-point intercept (Herrick et al. 2005). With this technique, only points that are not protected by some form of vegetation or litter are recorded as bare ground. In stands that are approaching canopy closure, the dominant western juniper canopy might mask higher amounts of bare ground, even when understory vegetation is severely lacking. However, it is unclear whether or not the methods used in this study are the cause for the lack of a significant relationship between western juniper canopy cover and bare ground.

As with other variables, the amount of bare ground following treatment varies depending on the methods of western juniper removal and the amount of soil disturbance and/or compaction. The results of this study indicate that treated sites tend to have less bare ground than untreated sites (Table 3). Bates et al. (2005) found that plant cover and litter were more evenly distributed on sites where western juniper had been cut, which implies that cutting of western juniper reduces bare ground. The fact that the treated sites in this study generally had less bare ground than untreated sites seems to imply that western juniper removal likely reduces soil erosion potential as well. This is significant from a management standpoint, because the relative amounts of bare ground, plant cover, and litter in an ecosystem can certainly affect not only soil erosion, but hydrologic processes and nutrient cycles as well.

Ecological Thresholds. Miller et al. (2005) have separated western juniper woodland succession into three transitional phases: subordinate, codominant, and dominant. Although they have no quantitative data to identity thresholds (transitions from one state or plant community to another) between these phases, they postulate that juniper begins to control many community processes as western juniper shifts from codominant to dominant. Although the level of dependent variable scatter evident in Figures 3 through 8 might be the result of highly variable study site characteristics such as soil texture, soil depth, and water-holding capacity, the reduction in scatter at around 20% canopy cover suggests the possibility of an identifiable threshold occurring earlier than the shift from codominance to dominance. As state and transition models that describe vegetation dynamics are incorporated into ecological site descriptions by USDA–NRCS, there is increased interest in threshold recognition and prediction to enable rangeland managers to prevent the occurrence of undesirable states and to promote desirable states (Briske et al. 2006).

Literature Cited

Arnold, J. F. 1964. Zonation of understory vegetation around a juniper tree. J. Range Manag. 17:41–42.

Bates, J., R. F. Miller, and T. Svejcar. 1998. Understory patterns in cut western juniper woodlands. Great Basin Nat. 58:363–374.

Bates, J., R. F. Miller, and T. S. Svejcar. 2000. Understory dynamics in cut and uncut western juniper woodlands. J. Range Manag. 53: 119–126.

Bates, J. D., R. G. Miller, and T. S. Svejcar. 2005. Long term successional trends following western juniper cutting. Rangeland Ecol. Manag. 58:533–541.

Belsky, J. A. 1996. Viewpoint: Western juniper expansion: is it a threat to arid northwestern ecosystems? J. Range Manag. 49:53–59.

Braun, C. E. 1998. Sage grouse declines in western North America: what are the problems? Proc. Western Assoc. State Fish and Wildlife Agencies 78:139–156.

Briske, D. D., S. D. Fuhlendorf, and F. E. Smeins. 2006. A unified framework for assessment and application of ecological thresholds. Rangeland Ecol. Manag. 59:225–236.

Buckhouse, J. C. and R. E. Gaither. 1982. Potential sediment production within vegetative communities in Oregon's Blue Mountains. J. Soil and Water Conserv. 37(2):120–122.

Bunting, S. C., J. L. Kingery, and E. Strand. 1999. Effects of succession on species richness of the western juniper woodland/sagebrush steppe mosaic. Pages 76–81 *in* S. B. Monsen and R. Stevens, compilers, eds. Proceedings: Ecology and Management of Pinyon–Juniper Communities Within the Interior West. Ogden, UT: USDA For. Ser. Gen. Tech. Rep. RMRS-P-9.

Burkhardt, J. W. and E. W. Tisdale. 1969. Nature and successional status of western juniper vegetation in Idaho. J. Range Manag. 22: 264–270.

Burkhardt, J. W. and E. W. Tisdale. 1976. Causes of juniper invasion in southwestern Idaho. Ecology 57:472–484.

Connelly, J. W. and C. E. Braun. 1997. Long-term changes in sage grouse (*Centrocercus urophasianus*) populations in western North America. Wildl. Biol. 3:229–234.

Dean, S., J. S. Burkhardt, and R. O. Meeuwig. 1981. Estimating twig and foliage biomass of sagebrush, bitterbrush, and rabbitbrush in the Great Basin. J. Range Manag. 34:224–227.

Evans, R. A. and J. A. Young. 1985. Plant succession following control of western juniper (*Juniperus occidentalis*) with picloram. Weed Sci. 33:63–68.

Gaither, R. E. and J. C. Buckhouse. 1983. Infiltration rates of various vegetative communities within the Blue Mountains of Oregon. J. Range Manag. 36:58–60.

Herrick, J. E., J. W. Van Zee, K. M. Havstad, and W. G. Whitford. 2005. Monitoring manual for grassland, shrubland and savanna ecosystems. Las Cruces, NM: USDA–ARS Jornada Experimental Range. 200 p.

Hickman, J. C. 1993. The Jepson Manual: Higher Plants of California. Berkeley, CA: University of California Press. 1400 p.

Hintze, J. 2004. NCSS and PASS. Kaysville, UT: Number Cruncher Statistical Systems.

Horman, C. S. and V. J. Anderson. 2003. Understory species response to Utah juniper litter. J. Range Manag. 56:68–71.

Miller, R. F., J. D. Bates, T. J. Svejcar, F. B. Pierson, and L. E. Eddleman. 2005. Biology, Ecology, and Management of Western Juniper. Oregon State University. Corvallis, OR: Agricultural Experiment Station. Technical Bulletin 152. 77 p.

Miller, R. F. and J. A. Rose. 1995. Historic expansion of *Juniperus occidentalis* (western juniper) in southeastern Oregon. Great Basin Nat. 55:37–45.

Miller, R. F., T. S. Svejcar, and J. A. Rose. 2000. Impacts of western juniper on plant community composition and structure. J. Range Manag. 53:574–585.

Miller, R. F. and P. E. Wigand. 1994. Holocene changes in semiarid piñon–juniper woodlands: response to climate, fire and human activities in the U.S. Great Basin. BioScience 44:465–474.

Pellant, M., J. E. Herrick, P. Shaver, and D. A. Pyke. 2005. Interpreting indicators of rangeland health. Version 4. Technical Reference 1734-6. Denver, CO: USDI, BLM, National Science and Technology Center. 122 p.

Pieper, R. D. 1990. Overstory–understory relations in piñon–juniper woodlands in New Mexico. J. Range Manag. 43:413–415.

Roberts, C. and J. A. Jones. 2000. Soil patchiness in juniper–sagebrush–grass communities of central Oregon. Plant Soil 223:45–61.

Rose, J. R. and L. E. Eddleman. 1994. Ponderosa pine and understory growth following western juniper removal. Northwest Sci. 68:79–85.

[SRM] Society for Range Management. 1999. A glossary of terms used in range management. Denver, CO: Society for Range Management. 20 p.

Tausch, R. J. and N. E. West. 1995. Plant species composition patterns with differences in tree dominance on a southwestern Utah piñon-juniper site. Pages 16–23 *in* D. W. Shaw, E. F. Aldon, and C. LoSapio, tech. coordinators, eds. Proceedings: Desired Future Conditions for Piñon–Juniper Ecosystems. Flagstaff, AZ: USDA Forest Service, General Technical Report RM-258.

Tausch, R. J., N. E. West, and A. A. Nabi. 1981. Tree age and dominance patterns in Great Basin piñon–juniper woodlands. J. Range Manag. 34:259–264.

Tiedemann, A. R. and J. O. Klemmedson. 1995. The influence of western juniper development on soil nutrient availability. Northwest Sci. 69:1–8.

Vaitkus, M. and L. E. Eddleman. 1987. Composition and productivity of a western juniper understory and its response to canopy removal. Pages 456–460 *in* R. L. Everett, ed. Proceedings: Piñon–Juniper Conference. Ogden, UT: USDA Forest Service, General Technical Report INT-215.

Vaitkus, M. and L. E. Eddleman. 1991. Tree size and understory phytomass production in a western juniper woodland. Great Basin Nat. 51:236–243.

West, N. E. 1993. Biodiversity of rangelands. J. Range Manag. 46: 2–13.

Wilcox, B. P. and D. D. Breshears. 1994. Hydrology and ecology of pinon–juniper woodlands: conceptual framework and filed studies. Pages 1009–1019 *in* D. W. Shaw, E. F. Aldon, and C. LoSapio, eds. Desired Future Conditions for Pinon–Juniper Ecosystems. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station. USDA Forest Service General Technical Report INT-258.

Young, J. A., R. A. Evans, and C. Rimbey. 1985. Weed control and revegetation following western juniper (*Juniperus occidentalis*) control. Weed Sci. 33:513–517.

Received June 11, 2007, and approved August 16, 2007.