

UNDERSTORY PATTERNS IN CUT WESTERN JUNIPER  
(*JUNIPERUS OCCIDENTALIS* SPP. *OCCIDENTALIS* HOOK.) WOODLANDS

Jon D. Bates<sup>1,2</sup>, Richard F. Miller<sup>1,3</sup>, and Tony Svejcar<sup>4</sup>

**ABSTRACT.**—Western juniper (*Juniperus occidentalis* spp. *occidentalis*) has rapidly expanded into shrub steppe communities in the Intermountain Northwest during the past 120 yr. Cutting juniper is a management tool used to restore shrub steppe communities. Response of the understory after cutting is strongly influenced by plant species composition existing prior to treatment. This study assessed distribution patterns of understory plants over 2 growing seasons after tree cutting in a western juniper woodland. Cover, density, and diversity of understory species were compared among 3 locations: interspaces, duff zones (previously under tree canopies), and debris zones (beneath cut trees). Plant cover and density increased in all zones following tree cutting. Understory vegetation in cut woodlands exhibited strong zonal distribution. Cover and density of *Poa sandbergii* and *Sitanion hystrix* and canopy cover of annual forbs were greatest in duff zones ( $P < 0.05$ ). Density and cover of other perennial grasses and total densities of perennial forbs and annual forbs were greatest in interspaces ( $P < 0.05$ ). Debris zones tended to have the lowest overall understory cover and plant density values. Under juniper debris many species common to interspaces were reduced in density, although plants that survived or established beneath debris grew larger than their counterparts in interspaces. Species that increased in density and cover under debris were plants characteristic of duff zones and whose seeds are typically wind dispersed.

*Key words:* western juniper, understory patterns, diversity, juniper debris, species composition, zonal succession.

Pinyon-juniper woodlands in the western United States have rapidly expanded into shrub-grasslands since the late 1800s (Tausch et al. 1981, West 1984, Miller and Wigand 1994). Western juniper (*Juniperus occidentalis* spp. *occidentalis* Hook.) has invaded extensive areas of sagebrush-grasslands and other plant communities in the Pacific Northwest (Burkhardt and Tisdale 1969, Miller and Rose 1995). The transition from shrub steppe communities to woodlands has resulted in reduced understory productivity and diversity (Johnson 1962, Jameson, 1967, Burkhardt and Tisdale 1976, Tausch et al. 1981, Tausch and Tueller 1990, Bates 1996). Understory distribution patterns in canopy and interspace zones become more distinctly developed during woodland development (Johnson 1962, Pieper 1990, Vaitkus and Eddleman 1991). Understory patterns probably reflect a mosaic of canopy and interspace microenvironments. Junipers influence the microenvironment under tree canopies by modifying temperatures and light levels (Pieper 1990), accumulating soil nutrients (Doescher

et al. 1987, Bates 1996), intercepting precipitation (Larsen 1993), and causing physical or allelopathic interference by litter layers (Jameson 1966, Peterson and Buss 1974). Padien and Lajtha (1992) attributed understory spatial patterns in pinyon-juniper woodlands to differences in nutrient availability, shade protection, seed dispersal, and seed germination.

Management prescriptions employed to reduce western juniper dominance in rangelands have been successful in increasing understory productivity and cover (Evans and Young 1984, Vaitkus and Eddleman 1987, Rose and Eddleman 1994, Bates 1996). However, the influence of spatial distribution on plant succession following juniper elimination, particularly with removal methods that leave substantial amounts of juniper debris on site, are poorly documented.

Evaluating understory distribution patterns may prove useful in generating hypotheses on species-zonal interactions and in predicting successional responses and pathways following juniper control. This study was designed

<sup>1</sup>Rangeland Resources Department, Oregon State University, Eastern Oregon Agricultural Research Center, Burns, OR 97720.

<sup>2</sup>Present address: Eastern Oregon Agricultural Research Center, Oregon State University, HC71, Hwy 205, Burns, OR 97720. (The Eastern Oregon Agricultural Research Center is operated jointly by the USDA-ARS and the Oregon Agricultural Experiment Station of Oregon State University.)

<sup>3</sup>Author to whom correspondence should be addressed.

<sup>4</sup>USDA—Agricultural Research Service, Hwy 205, Burns, OR 97720.

(1) to assess understory distribution patterns within an intact western juniper woodland prior to tree cutting and (2) to evaluate the effects of tree cutting on understory zonal patterns.

## METHODS

### Study Site

The study was conducted on Steens Mountain in southeastern Oregon, 9.5 km southeast of Diamond (118°36'W, 42°55'N). Elevation at the site is 1525 m and aspect is west-facing with a 22% slope. The site is dominated by an 80-yr-old western juniper woodland. Juniper canopy cover averaged 23%, and tree density averaged 228 trees ha<sup>-1</sup>. The following indicated a fully developed juniper stand: limited terminal and lateral leader growth on juniper trees, lack of juniper seedling recruitment, and most *Artemisia tridentata* spp. *vaseyana* Nutt. (mountain big sagebrush) were dead. Understory perennial plant basal cover averaged 2.5% in interspaces and 2.9% under tree canopies. Based on existing shrub/understory vegetation, soils, and aspect, we judged the original community, prior to woodland dominance, to have been *Artemisia tridentata* spp. *vaseyana*/*Stipa thurberiana* type.

Prior to treatment the dominant understory plant was *Poa sandbergii* Vasey (Sandberg's bluegrass), comprising nearly 75% of the total understory perennial plant basal cover. Other species characteristic of the site included *Stipa thurberiana* (Thurber's needlegrass), *Sitanion hystrix* (bottlebrush squirreltail), *Agropyron spicatum* (bluebunch wheatgrass), *Astragalus filipes* (basalt milkvetch), *Microsteris gracilis* (microsteris), and *Alyssum alyssioides* (pale alyssum).

Soils were classified as clayey-skeletal, montmorillonite, frigid Lithic Agrixerolls. They are shallow (40–50 cm deep) and are underlain by a thick, welded ash layer of rhyolite and rhyodacite composition, which limits root penetration.

Domestic livestock grazing has occurred on this site since the late 1800s. The ridge on which the study site is located was used as a sheep wintering area through the 1930s. Since the 1940s the site has been grazed by cattle in the early spring (April). Livestock were excluded from the site during our study.

Climate in southeastern Oregon is semiarid and continental. Winter and spring are typi-

cally cool and wet; summers are warm and dry. The majority of annual precipitation falls between November and June. Mean water year (1 October–30 September) precipitation at weather stations located 27 km southwest (elevation 1300 m) and 30 km northwest (1250 m) of the site average 28.2 and 24.9 cm, respectively.

### Experimental Design and Measurements

In June 1991 we established eight 0.8-ha replicated plots along the contour of the ridge slope. Plots were selected for similarities in overstory/understory cover and density, soil type, and aspect. After being measured for baseline vegetation characteristics (basal cover and density), juniper trees were felled with chainsaws in August 1991 on half of each plot (0.4 ha). Cut trees remained on the plots. We began subsequent measurements of understory characteristics and soil moisture content in April 1992 and concluded in September 1993. In this paper we report data from the cut plots only in order to highlight zonal differences.

Understory measurements were canopy and basal cover, density, and diversity. Sampling was spatially separated into 3 zones: duff, juniper debris, and interspace. Duff zones are defined as those areas formerly beneath tree canopies with a surface layer of old juniper needle litter. Debris zones are former interspace zones that are covered by felled juniper trees. Interspace zones are open areas that are not influenced by old or newly felled juniper tree litter.

We estimated understory plant density (1991–1993) and canopy cover (1993 only) for each zone in each replicate, in the 4 cardinal directions (for duff and interspace zones only), around 12 trees per replication, using a 30.5 × 61-cm frame (48 subsamples per zone per replication). Trees were randomly selected each year. For the debris zone we estimated density and cover by randomly subsampling 4 locations under each of the 12 cut trees in each replication. We subsampled along the outer 1/3 of the duff zone. Interspace zones were located approximately 3 m from the outer edge of the duff zone or at the midpoint between duff zones.

Using the cover class technique described by Daubenmire (1959), we estimated canopy cover.

In this study 7 cover classes were designated: trace (0–1%), I (1–5%), II (5–25%), III (25–50%), IV (50–75%), V (75–95%), and VI (95–100%). Midpoints of cover classes were used for statistical analysis.

Understory basal cover of perennial grasses and forbs was measured along five 30.5-m line intercepts positioned parallel to the slope in all 8 cut plots in 1991 (baseline year, prior to cutting), 1992, and 1993. Transects were permanently marked in 1991 using rebar stakes. Groundcover provided by juniper debris and old juniper litter in duff locations was also estimated along the transects.

Gravimetric soil water content was sampled in interspace and debris zones at 2 depths, 0–20 and 20–40 cm. We collected biweekly samples on 12 dates during the 1992 growing season (April–September) and on 13 dates during the 1993 growing season. In each plot 5 randomly located subsamples were collected for each zonal depth during each measurement period. Soils were weighed, oven dried at 106°C for 48 h, and reweighed to determine percent water content.

#### Statistical Analysis

Understory data were compared among zones over time using ANOVA techniques for a randomized block design. Main effects were year and zone. Understory measurements were also analyzed each year to help explain year-by-zone interactions. Subsamples of understory density and canopy cover were averaged by zone per replicate for statistical analysis ( $n = 8$  for each year). Soil water content was analyzed each year using a repeated-measures ANOVA for a randomized block design. Main effects were zone and soil depth.

All statistical analyses were performed using the Statistical Analysis System (SAS Institute 1988). Data were tested for normality using the SAS univariate procedure. Data not normally distributed were log transformed to stabilize variance. When interactions were significant, means were separated using Duncan's new multiple range test. The alpha level was set at  $P < 0.05$  for statistical significance.

Diversity indices were determined for each zone using density measurements in 1992 and 1993. Hill's (1973) N1 and N2 diversity indices were used as indicators of plant diversity. The N2 index is a measure of very abundant species and the N1 index is a measure of

abundant species. Hill's modified evenness ratio was used to compare relative abundances of species among zones (Ludwig and Reynolds 1988).

## RESULTS

### Climate Conditions and Soil Water

Water year (30 September–1 October) precipitation values were 20% below average in 1991 and 1992 at weather stations 27 and 30 km from the site. Study site precipitation in the 1992 water year totaled 21.3 cm, half of which was received in June and July 1992. The 1993 growing season was cooler and eastern Oregon received record amounts of moisture. Precipitation totals at nearby weather stations were 140% and 149% of long-term averages, respectively. Water year precipitation on the study site totaled 41.8 cm.

In 1992 soil moisture at both depths was significantly greater ( $P < 0.05$ ) in debris zones than in interspaces from late June through September (Fig. 1). In 1993 soil water at 0–20 cm depth was significantly greater under debris than in the interspace (Fig. 1A). Except for 2 periods, mid-May and July, there were no differences in soil water content at 20–40 cm between the 2 zones in 1993 (Fig. 1B).

There were significant time-by-zone-by-depth interactions for soil water in 1992 and 1993 ( $P < 0.05$ ). These interactions indicated that soil water decreased as the growing season progressed and was greater at both depths in the debris zone than in the interspace. Depth-by-zone ( $P < 0.05$ ) interactions indicate that soil water was greater at 20–40 cm than 0–20 cm in the soil profile.

### Understory Density and Cover

PRETREATMENT VEGETATION PATTERNS.—Perennial plant basal cover in interspace and duff locations was very low prior to the cutting treatment (Fig. 2A). Total plant basal cover did not differ between zones. However, for several species we detected significant differences in cover between zones. Basal cover of *Poa sandbergii* and *Sitanion hystrix* was greater in duff zones than in interspaces ( $P < 0.05$ , Fig. 2A). Basal cover of *Stipa thurberiana* was highest in interspaces ( $P < 0.05$ ). Densities of *Poa* and *Sitanion* were greater in the duff zone than in interspaces ( $P < 0.05$ , Fig. 3A). Density of *Stipa*, *Agropyron spicatum*, and *Allyssum allyssoides*

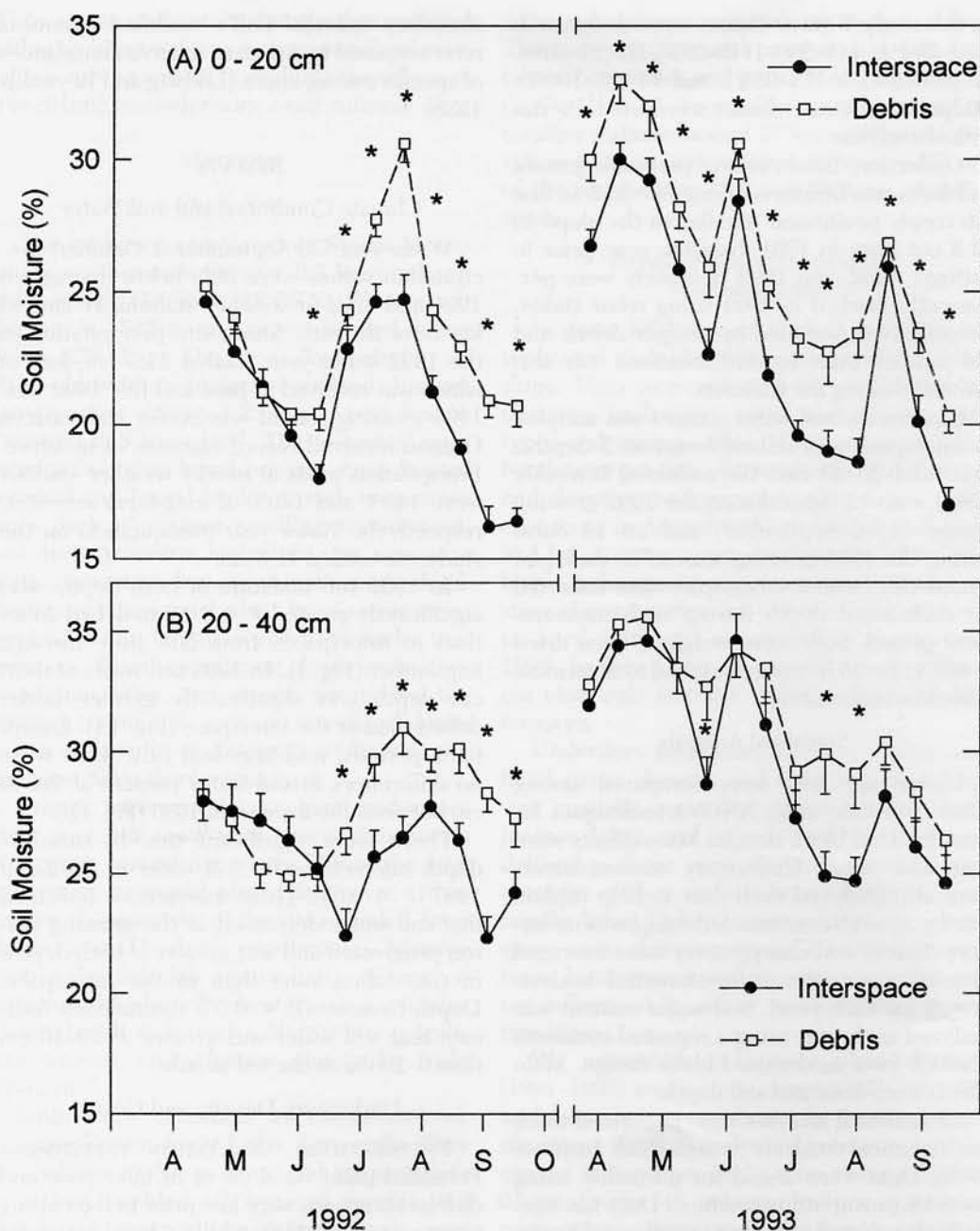


Fig. 1. Volumetric soil water content in interspace and debris zones from (A) 0–20 cm and (B) 20–40 cm depths during the 1992 and 1993 growing seasons. Data are in means  $\pm$  s.e. Asterisks (\*) denote significant differences between zones ( $P < 0.05$ ).

was greater in interspaces than in the duff zone ( $P < 0.05$ , Figs. 3A, 4A). Density values for annual forbs in 1991 are probably low and incomplete because sampling did not take place until July, well past the peak for annual forb growth.

POSTTREATMENT VEGETATION PATTERNS.—Cover and density of understory species differed significantly among debris, interspace, and duff zones ( $P < 0.05$ ) after cutting (Figs. 2–4). Cover of perennial plant species and density of most other understory species



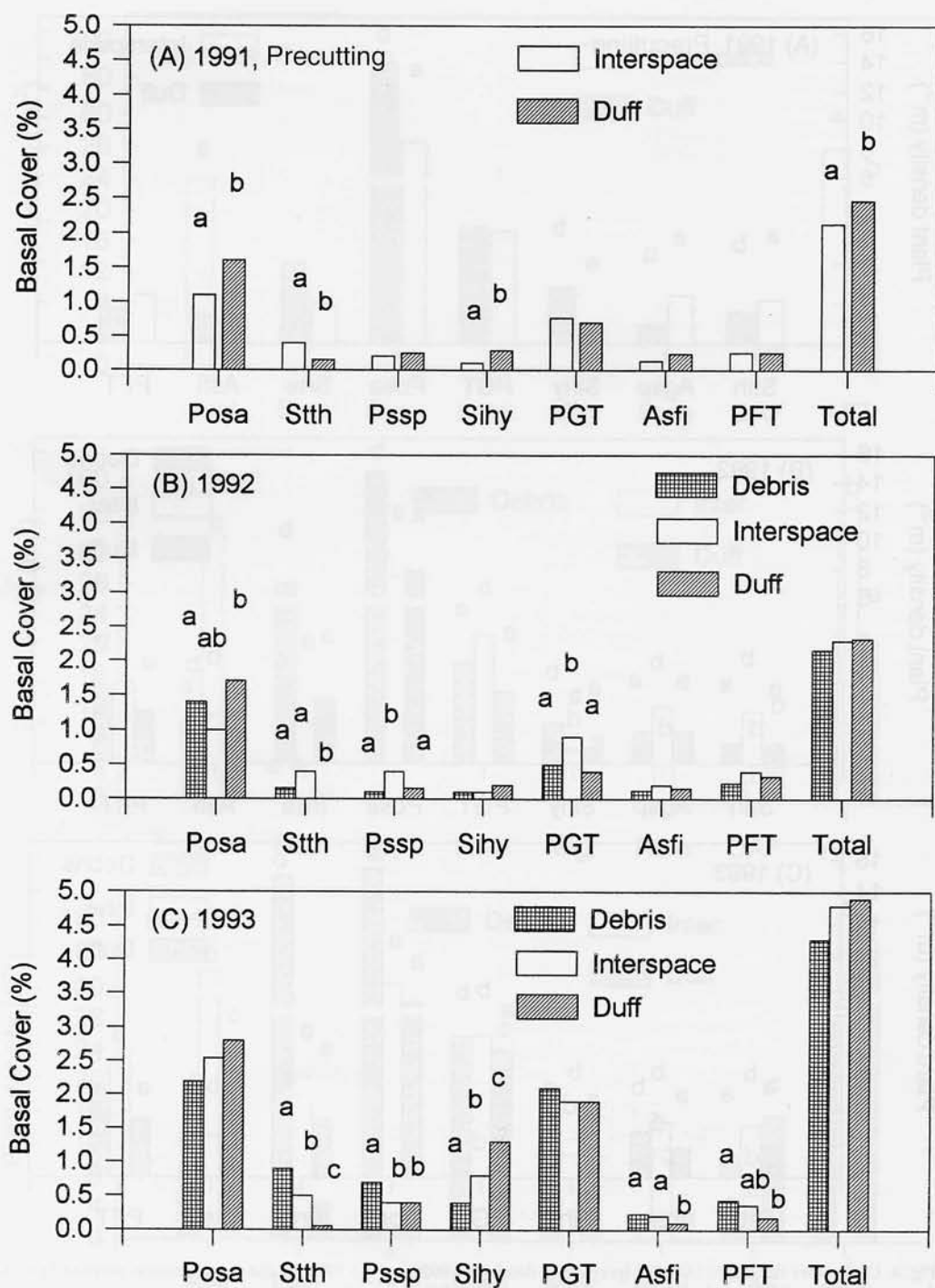


Fig. 2. Understory basal cover in (A) 1991 (precutting data), (B) 1992, and (C) 1993 for the most common perennial plants. Different letters denote significant zonal differences ( $P < 0.05$ ) between species or plant groups. Species abbreviations: Posa—*Poa sandbergii*; Sthh—*Stipa thurberiana*; Agsp—*Agropyron spicatum*; Sihy—*Sitanion hystrix*; PGT—perennial grass total; Brte—*Bromus tectorum*; Asfi—*Astragalus filipes*; PFT—perennial forb total.

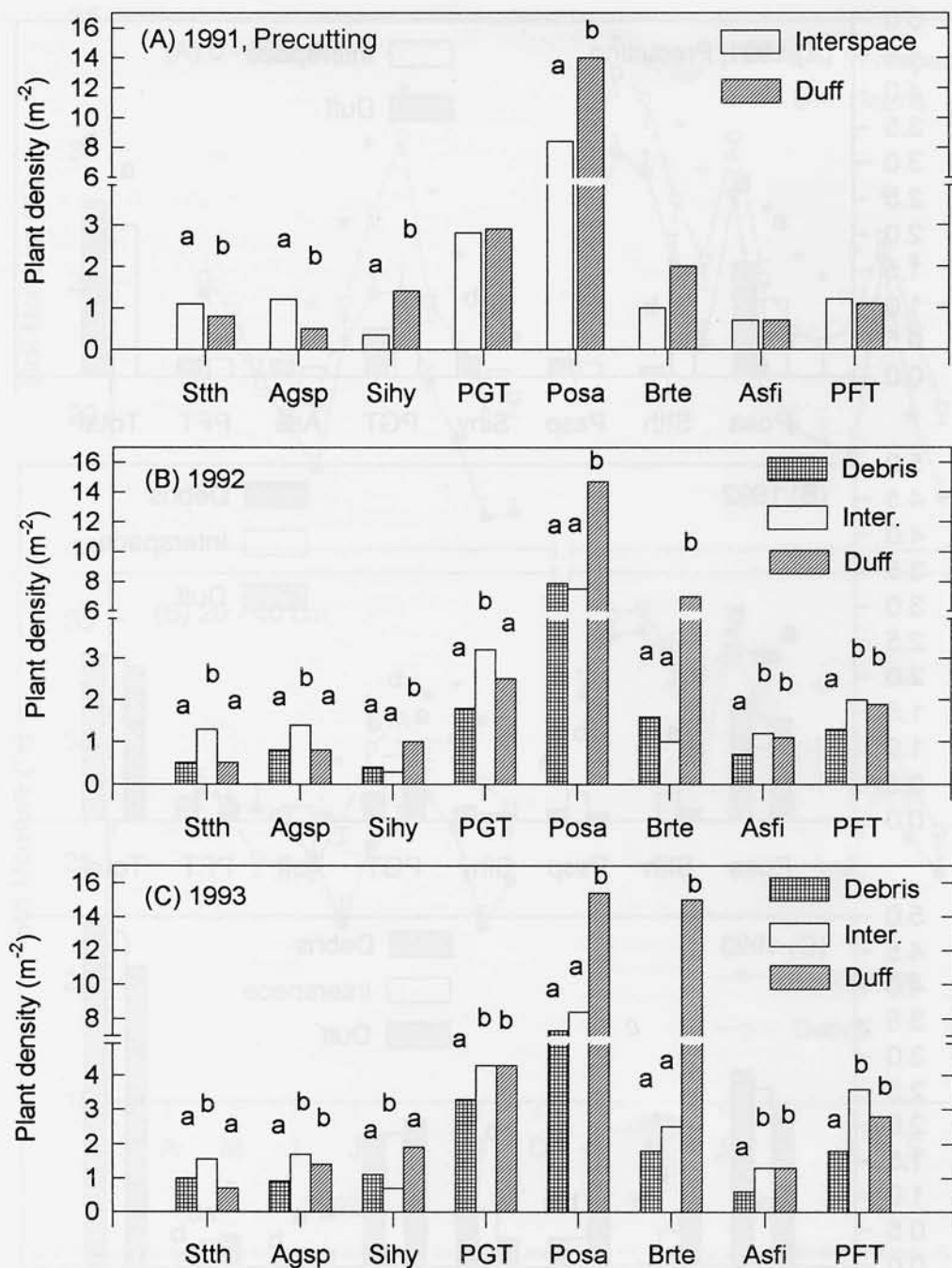


Fig. 3. Understory density in (A) 1991 (precutting data), (B) 1992, and (C) 1993 for the most common perennial plants and annual grasses. Different letters denote significant zonal differences ( $P < 0.05$ ) between species or plant groups. Species and plant group abbreviations are defined in Figure 2.

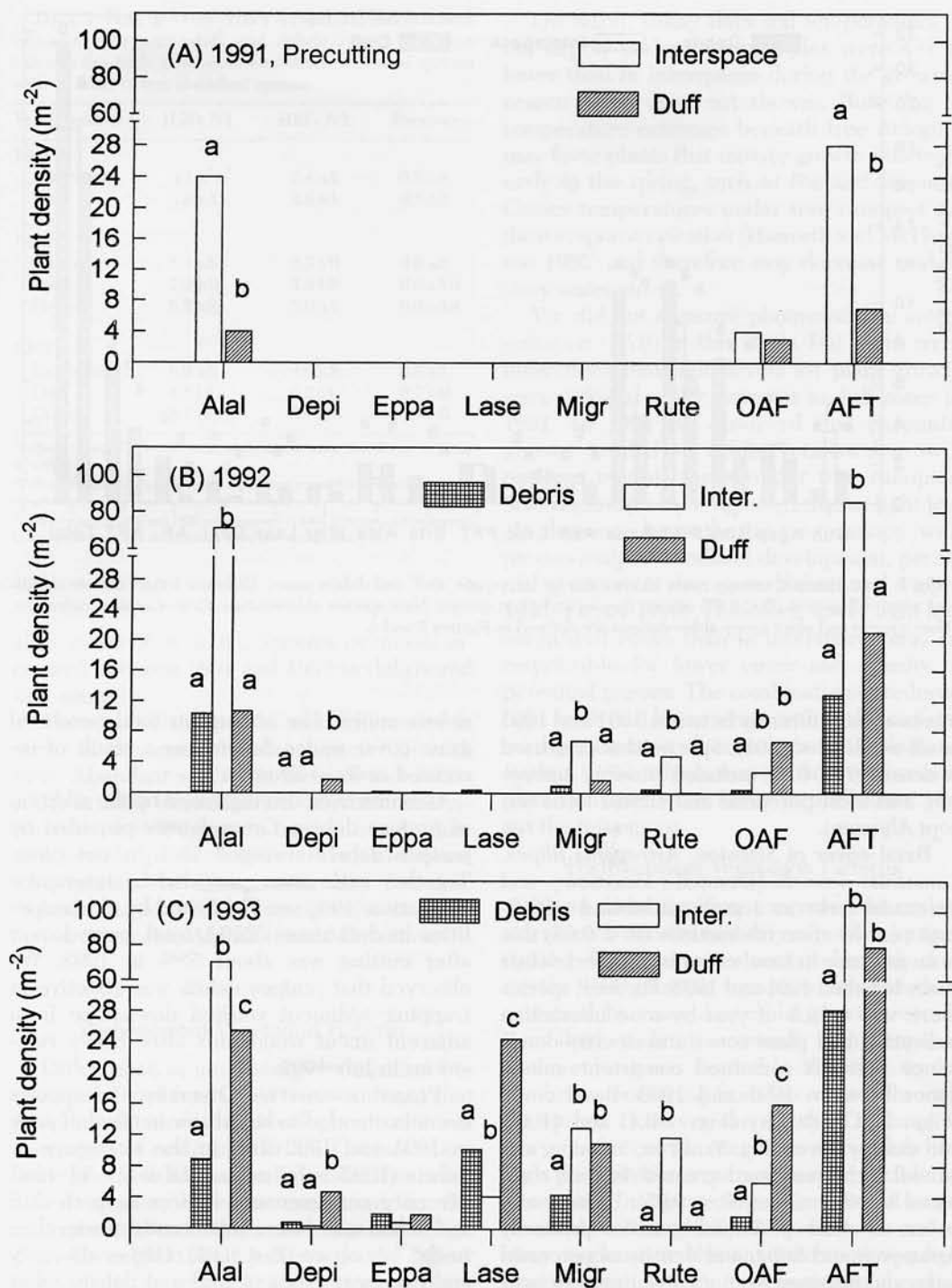


Fig. 4. Annual forb density in (A) 1991 (precutting data), (B) 1992, and (C) 1993. Different letters denote significant zonal differences ( $P < 0.05$ ) between species and plant groups. Species abbreviations: Alal—*Alyssum alyssioides*; Depi—*Descurainia pinnata*; Eppa—*Epilobium paniculatum*; Lase—*Lactuca serriola*; Migr—*Microsteris gracilis*; Rute—*Ranunculus testiculatus*; OAF—other annual forbs (e.g., *Cirsium* spp., *Gilia* spp.); AFT—annual forb total.

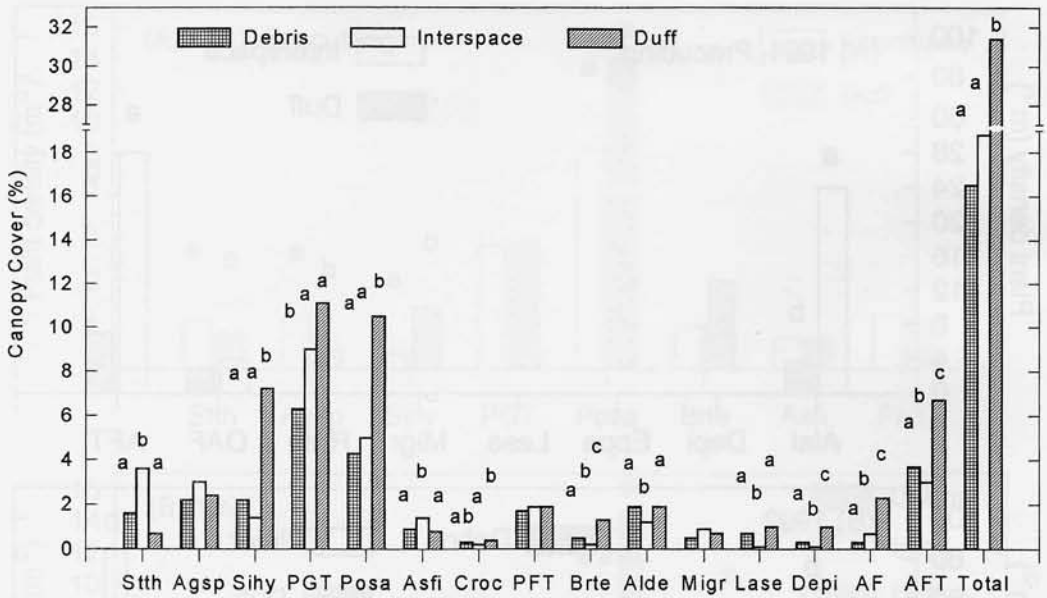


Fig. 5. Posttreatment canopy cover (%) in 1993 for interspace, duff, and debris zones. Different letters denote significant zonal differences ( $P < 0.05$ ) among species and plant groups. New species abbreviation: Croc—*Crepis occidentalis*. Other species and plant group abbreviations are defined in Figures 2 and 4.

increased significantly between 1991 and 1993 in all zones ( $P < 0.01$ ). Species that increased in density ( $P < 0.05$ ) included *Sitanion*, *Agropyron*, and most perennial and annual forbs (except *Alyssum*).

Basal cover of *Sitanion*, *Astragalus filipes*, *Lomatium donnelli* (Donnell's lomatium), and perennial forbs as a group exhibited significant year-by-zone interactions ( $P < 0.05$ ) due to an increase in basal cover in duff and debris zones between 1991 and 1993. For most species there was a lack of year-by-zone interaction indicating that plant cover and density-dominance patterns remained consistent among zones between 1991 and 1993. Basal cover (Figs. 2B,C), density (Figs. 3B,C and 4B,C), and canopy cover (Fig. 5) of *Poa*, *Sitanion*, and annual forbs remained greatest in duff compared to other zones ( $P < 0.05$ ). Density and cover of other perennial grasses, primarily *Agropyron* and *Stipa*, and density of perennial forbs and *Alyssum* were greater in interspaces than in either duff or debris zones ( $P < 0.05$ ).

Canopy cover and density of *Sitanion* and canopy cover of annual forbs tended to be greater in debris zones than in interspaces ( $P < 0.05$ ). Between 1992 and 1993 basal cover of perennial grasses increased fourfold in

debris zones. The change in total perennial grass cover under debris was a result of increased cover of *Sitanion*.

Groundcover also increased by the addition of juniper debris. Groundcover provided by juniper debris averaged 18% in cut plots. Together with cover provided by interspace vegetation (18%, see Fig. 5) and by old juniper litter in duff zones (22%), total groundcover after cutting was about 58% in 1993. We observed that juniper debris was effective in trapping sediment washed downslope from adjacent uncut woodlands after heavy rainstorms in July 1992.

PLANT DIVERSITY.—Diversity and species evenness tended to be greater in the duff zone in 1991 and 1992 than in the interspace or debris (1992 only) zones (Table 1). In 1993 diversity and evenness indices in both duff and debris zones were significantly greater than in the interspace ( $P < 0.05$ ). Higher diversity and evenness ratios in duff and debris zones compared to the interspace were due to higher species richness of annual forbs and lower densities of *Alyssum* and *Microsteris gracilis*. The high densities of *Alyssum* reduced evenness and diversity in interspace zones. Plant diversity increased between 1991 and 1993 in



TABLE 1. Plant diversity (Hill's N1 and N2) and evenness ratios in interspace, duff, and debris zones. Evenness ratios in this table show a co-dominance of several species with an array of less abundant species.

Year/Location	Hill's N1	Hill's N2	Evenness
1911			
Interspace	3.1 a <sup>1</sup> A <sup>2</sup>	2.4 aA	0.5 aA
Duff	3.6 aA	2.6 aA	0.5 aA
1992			
Interspace	5.1 aB	3.5 aB	0.6 aA
Duff	7.0 bB	4.9 bB	0.6 aAB
Debris <sup>3</sup>	5.2 aB	3.6 aA	0.6 aAB
1993			
Interspace	5.9 aB	4.0 aB	0.5 aA
Duff	8.5 bC	6.2 bC	0.7 bB
Debris	8.7 bC	6.3 bB	0.7 bB

<sup>1</sup>Different lowercase letters indicate significant zonal differences in a year ( $P < 0.05$ ).

<sup>2</sup>Different uppercase letters denote significant year differences within a zone ( $P < 0.05$ ).

<sup>3</sup>Debris values in 1992 and 1993 are compared to 1991 interspace value because before cutting in 1991 debris zones were interspace areas.

all 3 zones ( $P < 0.05$ ). Species evenness increased between 1991 and 1993 in debris and duff zones.

There were similarities and differences in terms of the most abundant species in each zone. Abundant species in the duff and debris zones in 1993 were *Alyssum*, *Microsteris*, *Descurainia pinnata* (pinnate tansymustard), *Lactuca serriola* (prickly lettuce), *Bromus tectorum* (cheatgrass), *Astragalus*, *Poa*, and *Sitanion*. Abundant species in the interspace were *Agropyron*, *Stipa*, *Poa*, *Alyssum*, and *Microsteris*.

## DISCUSSION

### Pretreatment Vegetation Patterns

Differences in understory composition between duff and interspace zones indicate that juniper influences the development of zonal microsites. Conditions in duff zones were more favorable for *Poa* and *Sitanion* than associated species, whereas conditions in the interspace favored *Stipa* and *Alyssum* (Figs. 2–5). These plant zonal patterns do not appear to be related to soil moisture content, as there were no differences detected in soil moisture availability between duff and interspace zones (Bates 1996). Duff and interspace understory patterns may be related to other factors influencing plant establishment and growth, such as temperature, light, and nutrient availability.

On warm, sunny days soil temperatures (5 cm depth) under tree canopies were 4–7°C lower than in interspaces during the growing season (1993 data, not shown). Buffering of temperature extremes beneath tree canopies may favor plants that initiate growth relatively early in the spring, such as *Poa* and *Sitanion*. Cooler temperatures under tree canopies reduce evapotranspiration (Haworth and McPherson 1995) and therefore may decrease understory water stress.

We did not measure photosynthetic active radiation (PAR) in this study, but there were indications that light levels for plant growth were reduced under canopies in duff zones in 1991. In 1991 we observed that perennial grasses tended to exhibit etiolated growth patterns in duff zones under tree canopies. Several studies have reported that as light levels decrease beneath the tree canopy with pinyon-juniper woodland development, perennial grass cover decreases (Schott and Pieper 1985, Pieper 1990). Therefore, lower light levels in duff zones than in interspaces may be responsible for lower cover and density of perennial grasses. The combination of reduced light levels and lower temperatures also reduces seed germination of annual plants (Baskin and Baskin 1985), which may explain why annual plant densities were lower in duff zones versus the interspace.

### Posttreatment Vegetation Patterns

There were significant increases in understory cover, density, and diversity after juniper cutting. These increases occurred mainly during the 1993 growing season, which was characterized by more favorable growing conditions (higher spring moisture). Plant response to the cutting was limited in 1992 due to dry conditions occurring from late winter through the spring. However, the ability of the understory in the cut treatment to respond in the high precipitation year was made possible by eliminating juniper competition for soil moisture and N (Bates 1996). We believe the understory response in the cut treatment resulted from elimination of juniper competition because in adjacent uncut woodland the understory showed little response to increased precipitation in 1993 (Bates 1996).

Zonal understory plant composition did not change in duff or interspace zones after cutting. Species with greater cover (Figs. 2, 5) or

density (Figs. 3, 4) in duff zones, such as *Poa* and *Sitanion*, remained dominant in the duff zone while *Stipa*, *Agropyron*, and *Alyssum* remained dominant in the interspaces. These results suggest that early postcutting understory composition, particularly for zonal dominants, is predictable based on pretreatment understory floristics. Predicting understory dynamics after cutting, however, provides only a qualitative estimate. Predicting a quantitative response is more difficult due to a number of uncertainties, particularly postcutting weather conditions. Uncertainty is also introduced by lack of knowledge about the quantity and composition of soil seed bank reserves (Koniak and Everett 1982) and the level of understory seed production following release from juniper competition. For instance, the increase in plant diversity and species richness (Table 1) in our study appears to have largely resulted from the emergence of plants from soil seed banks and belowground bulbs and tubers. Understory succession following pinyon-juniper removal by fire is also guided by initial site floristics, although prediction of posttreatment response is again limited to qualitative estimates (Everett and Ward 1984).

After cutting, plant cover increased more than did density, especially for perennial plants, because existing perennial plants grew larger in size. Between 1991 and 1993 total perennial grass basal cover increased by nearly 200%, but perennial grass densities increased by only 65% in duff zones and 43% in interspaces. The lower density response of perennial grasses was due to the lack of seed production. Except for *Sitanion*, little seed production in the perennial component was observed in 1991 or in 1992. In 1993 we observed that perennial grasses allocated a large portion of their growth to reproduction. The higher perennial seed crop in 1993 may alter plant composition on the site in subsequent years.

Litter layers in duff zones continued to influence species establishment and growth following cutting. Plant density and cover were greatest in the outer portion of the duff zone, decreasing with proximity to the tree stump where litter depth was greatest (Bates 1996). In other pinyon-juniper woodlands, plant density and cover decreased as the tree bole was approached and litter layers thickened (Everett and Sharrow 1985, Dye et al. 1995). Juniper litter may interfere with seed germination and

seedling establishment by physically impeding seed-soil contact, reducing soil temperatures, and restricting plant growth via allelopathy (Jameson 1966, Peterson and Buss 1974). Although allelopathic effects should not be discounted, they seem unlikely given growth patterns of plants established in duff areas. Plants that were established or became established in the duff zone tended to grow larger than their counterparts in the interspace, particularly annual grasses and forbs.

There was a propensity for greater establishment of *Sitanion* and several annual forbs (*Lactuca*, *Cirsium* spp. [thistles]) in duff zones than in interspaces. This may be a product of seed dispersal and catchment mechanisms. Seeds of *Sitanion* and these annual forb species are typically wind dispersed. We hypothesized that old juniper needle litter in duff zones is more effective in trapping wind-dispersed seeds than the relatively bare soil surfaces characterizing the interspaces.

Juniper debris had negative and positive effects on understory plants. Prior to cutting in 1991 debris zones were interspaces. After trees were cut and debris zones created, composition of the understory shifted, developing greater similarity to duff zones than to interspace zones. In both years following juniper cutting, cover and density of *Sitanion* and the following wind-disseminated annual forbs increased under juniper debris: *Lactuca*, *Epi-lobium paniculatum* (willow-weed), and *Cirsium* spp. These plants tended to establish along the outer edges and less heavily shaded or open patches of the debris zone. These results indicate that microenvironmental changes can alter species composition and successional pathways.

The increase in *Sitanion* density under debris suggests that debris also may be beneficial for establishment of other grass seedlings. Once needles fall from the debris and sufficient perennial grass seed sources are available, juniper debris may serve as important microsites for other perennial grass seedlings.

Total annual forb density and cover and density of perennial grasses (except *Sitanion* and *Poa*) and perennial forbs were still significantly lower under debris than in interspaces ( $P < 0.05$ ) in 1992 and 1993. Negative effects of juniper debris on perennial grasses (except *Sitanion* and *Poa*) and forbs were particularly evident in 1992 when compared to interspace

values in 1991. Perennial grasses, such as *Stipa*, and forbs (e.g., *Astragalus*) were killed under heavy debris accumulations as evidenced by their reduced densities.

The negative impact of juniper debris on annual forbs, particularly *Alyssum* and *Microsteris*, may have resulted from lowered seed germination and/or plant establishment. Diminished light levels and lower soil temperatures due to shading by juniper debris may reduce seed germination and establishment of annual forbs, thus resulting in decreased forb density. However, annuals and perennials that did establish in debris were generally larger and stayed active longer into the season than their counterparts in the interspaces (Bates 1996).

The larger individual sizes of plants and their prolonged growing season under debris may have been a product of improved plant-water relations. Higher soil moisture levels (Fig. 1) under debris are hypothesized to have resulted from a combination of reduced evaporative loss and lower moisture demand by plants. Reduced temperatures and increased boundary layers provided by pinyon-juniper debris lower vapor pressure gradients, thereby reducing transpirational demand (Gifford and Shaw 1973). The lower density of plants under debris also may have resulted in more available resources per plant than in the interspace, thus contributing to larger plant size.

Results from this study support findings from other pinyon-juniper systems that understory plant composition is influenced by zonal location. There has been little discussion about the effects on understory zonal patterns of juniper removal by cutting, fire, or other means. Our study determined that while there were significant increases in plant cover and density resulting from juniper removal, there was little change in relative species (understory zonal dominates) composition in duff or interspace zones. Predicting qualitative species composition in duff and interspace zones, at least in the first 2 yr postcutting, is possible from pretreatment community floristics. Understory response to the deposition of juniper debris is less predictable. Changes to the microenvironment caused by juniper debris rapidly shifted understory plant composition. How juniper debris affects vegetation dynamics over a longer period of time is currently being monitored on this site. We hypothesize that overall plant community composition and development will

not be radically altered by juniper debris since debris coverage averages only 18% across the site.

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