AN ABSTRACT OF THE THESIS OF

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Title: Effect of Western Juniper on Understory Herbage Production in Central Oregon

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Lee E. Eddleman

Evidence suggests that western juniper (Juniperus occidentalis) in Central Oregon affects understory production and composition. As trees increase in size and density, understory production is reduced and composition changes. This study was designed to identify the relationship between production and composition of understory vegetation and various tree canopy sizes of western juniper, and to describe the responses of understory vegetation to removal of western juniper. Understory production was sampled in 1983 and 1984 by clipping plots on an individual trees basis from areas with trees present

and areas from which trees had been removed in 1982. Biomass production was determined from trees within three canopy diameter size classes and from two zones, beneath the canopy and in the interspace. Production was examined on two sites, a lower slope, shallow soil site and an upper slope, moderately deep soil site.

Some year-to-year differences in production of individual species and specific tree sizes may be explained by variation in precipitation during critical growth periods the two years of the study. Sandberg bluegrass and, possibly, Idaho fescue production may have been greater in 1983 than 1984 due to variation in late spring precipitation, especially on shallow soils associated with small trees.

Differences in patterns of production of individual species were most clearly developed associated with large, rather than small and intermediate trees. Cheatgrass, squirreltail, bluebunch wheatgrass, and Idaho fescue were common beneath the canopy, while Sandberg bluegrass was common in the interspaces. Cheatgrass and perennial forb production beneath the canopy increased with tree size. Production of other species, such as Sandberg bluegrass, was apparently not affected by tree size.

Canopy removal resulted in species-specific increases in biomass production both years. Production increases were greater beneath the canopy than in the interspaces. Perennial grasses provided small variable production increases beneath the canopy of large trees. Annual grasses, primarily cheatgrass, and annual forbs, primarily Epilobium paniculatum, contributed most to elevated productivity the first two years following juniper removal. Cheatgrass response was mainly associated with large trees, while annual forb response was independent of tree size. Sandberg bluegrass production seemed more closely tied to growing season precipitation than to canopy removal, regardless of tree size.

Effect of Western Juniper on Understory Herbage Production in Central Oregon

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Milda R. Vaitkus

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INTRODUCTION

Establishment of undesireable plants on western rangelands is a major concern of land managers. Some introduced and native species expand into areas from which they were historically absent and compete with desired vegetation. This competition can result in reduction in plant productivity and a change in plant composition. Since some invading species may also be less palatable to livestock, the forage base can, potentially, be diminished.

Western juniper (_Juniperus occidentalis_ Hook ssp. _occidentalis_) (Vasek 1966) is such an invading species. Historically, this small to medium-sized, long-lived tree was limited to open stands on mountain slopes and high plateaus, primarily associated with desert-grassland type vegetation, and bordering or occurring in patchy areas within the ponderosa pine

(*Pinus ponderosa*) type (Sowder and Mowat 1958). Over the past one hundred years, however, it has established in mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*)-perennial bunchgrass communities as dense scattered stands or continuous forests (Burkhardt and Tisdale 1969). Expansion of western juniper into these communities has been cited as a direct cause of decline in palatable forb and grass production (Bedell and Bunch 1978).

Although western juniper associations have been identified and described (Driscoll 1964a, Eckert 1957), localized influences of individual trees on soil properties, understory plant composition, and understory forage production are poorly understood. Observations indicate western juniper outcompetes other plants by utilizing a greater proportion of available water resources (Jeppeson 1978). Quantitative evidence for causes and effects of western juniper expansion is lacking. Results of studies in pinyon-juniper communities (Dwyer 1975) that examined overstory and understory relationships are usually applied to management of western juniper woodlands. Studies of western juniper, however, suggest western juniper communities may not respond to management in the same manner as pinyon-juniper communities (Evans and Young 1985).

The objectives of this study were to: 1) identify relationships of understory vegetation production and composition with various canopy sizes of western juniper, and; 2) describe responses of understory vegetation to removal of western juniper.

LITERATURE REVIEW

Western juniper (*Juniperus occidentalis* Hook. ssp. *occidentalis*) (Vasek 1966) is widely distributed in the Intermountain Northwest. Its greatest concentration is in central and eastern Oregon, but it also extends to northern California, northern Nevada, southwestern Idaho, and eastern Washington (Dealy, et al. 1978b). In Oregon, western juniper is the major vegetative component on over 717,600 ha (1,773,190 Ac) (Forest-Range Task Force 1972). The center of western juniper development appears to be in the large continuous woodlands it forms in Deschutes, Crook, and Jefferson Counties in central Oregon (Dealy et al. 1978b).

The Western Juniper Zone, found almost exclusively in dry interior regions, is the most xeric of the tree-dominated zones in the Pacific Northwest (Franklin and Dyrness 1973). At the center of this zone, the climate is continental, but modified by Pacific marine air (Dealy et al. 1978a). The region is semi-arid; summer temperatures may reach a maximum of

46° C (115°F) and winter temperatures of -47°C (-53°F) have been recorded. The frost-free period averages 130 days per year (Sowder and Mowat 1958). Precipitation of 250 to over 510 mm (10 to 20 in) occurs principally as snow in winter and rain in spring and fall. Approximately two-thirds of total yearly precipitation occurs as snow. Precipitation during the summer occurs primarily as intermittent, but intense storms. As a result of high daytime temperatures, moisture from these summer storms is unavailable for plant growth (Driscoll 1964b). Thus, moisture and temperature act to limit plant growth in this zone.

The altitudinal range of western juniper is from sea level to 459 m (1800 ft) near the Columbia River (Sowder and Mowat 1958), 670-1525 m (2200-5000 ft) on the plateaus of central Oregon, and 1220-1525 m (4000-5000 ft) in northeastern California. Subspecies australis extends up to 3233 m (10,600 ft) in the high Sierra. Much of central Oregon juniper woodland occurs on level to rolling topography on slopes of less than 7% and at elevations of 750-1495 m (2450-4900 ft) in Jefferson and Deschutes counties (Dealy et al. 1978a, Martin 1980). Western juniper is found less continuously on alluvial fans, low terraces, canyon sideslopes, and steep escarpments (Dealy et al.

1978b). Scattered junipers are found on relatively flat topography in rocky areas; occasional trees are found on steep rockland or tallus slopes (Dealy et al. 1978a). It occurs on essentially all exposures and slopes. Although establishment of juniper seedlings is better on deep, poorly drained bottom sites, a higher growth rate occurs on upper, well-drained sites (Burkhardt and Tisdale 1976).

Soils supporting western juniper have developed from a variety of parent materials including igneous, sedimentary, and metamorphic rock (Dealy et al. 1978a). Soil mixtures may be nearly homogeneous or highly stratified. These varying physical environments result in the ability of western juniper to establish over a broad spectrum of conditions.

Soils of this zone have evolved under aridic and xeric moisture regimes and include Camborthids, Haplargids, and Haploxerolls soil great groups. Surface soils typically have an ochric epipedon, are coarse-loamy, low in organic matter, and slightly acidic (pH approximately 6.0) to neutral (Franklin and Dyrness 1973). Subsoils typically have calcareous or siliceous deposits on peds or rocks, and weak profile development (Dealy et al. 1978b). Average soil depth is 76 cm (30 in) although roots may penetrate underlying cracked bedrock.

Western juniper communities are commonly found between desert or perennial bunchgrass areas and ponderosa pine (Pinus ponderosa) zones (Sowder and Mowat 1958). Associated vegetation includes sagebrush (Artemisia spp.), rabbitbrush (Chrysothamnus spp.), and antelope bitterbrush (Purshia tridentata). Western juniper also occurs in mixtures with ponderosa pine, usually on poor pine sites.

Driscoll (1964b) described 43,740 ha (108,000 Ac) in Crook, Deschutes, and Jefferson Counties in Central Oregon with western juniper as the major species and identified 9 communities and 2 variants. Driscoll's (1962) associations show a variety of western juniper co-dominants. Three of his associations, Western juniper/ Idaho fescue (Juniperus occidentalis/Festuca idahoensis), Western juniper/ bluebunch wheatgrass (Juniperus occidentalis/Agropyron spicatum), and Western juniper/ bluebunch wheatgrass-Idaho fescue (Juniperus occidentalis/Agropyron spicatum-Festuca idahoensis) have understories dominated by grass; the other 6 have understories of big sagebrush (Artemisia tridentata ssp.). Franklin and Dyrness (1973) considered a Juniperus/ Artemisia/

Agropyron association a climatic climax. This association occurs on well-drained loamy soils and may include gray rabbitbrush (Chrysothamnus nauseosus), Thurber's needlegrass (Stipa thurberiana), Sandberg bluegrass (Poa sandbergii), nineleaf lomatium (Lomatium triternatum), cheatgrass brome (Bromus tectorum), and western fescue (Festuca occidentalis).

In southeastern Oregon Eckert (1957) described 4 western juniper associations in northern Harney and Lake Counties. He concluded western juniper and Idaho fescue had similar growth requirements and were near the limit of their tolerance range on the same habitats. Hall (1973) described 4 western juniper communitites in the Blue Mountains of Oregon, occurring primarily on shallow rocky soils. Burkhardt and Tisdale (1969, 1976) studied 2 major western juniper communities in southwestern Idaho; fractured bedrock provided sites for establishment of western juniper seedlings and the amount of rock was directly correlated to canopy cover and number of trees on climax sites.

Western juniper/ bluebunch wheatgrass and Western juniper/ bluebunch wheatgrass-Idaho fescue communities usually occupy level to hilly sites in mountainous areas where moisture is lower than in the sagebrush steppe (Dealy et al. 1978a). In these stands western juniper occurs primarily as a single overstory species with wide spacing. Crown cover is usually less than 35%, with big sagebrush as the dominant shrub, and gray rabbitbrush (Chrysothamnus nauseosus) and green rabbitbrush (Chrysothamnus vicidiflorus) present in varying amounts. On moist sites, the shrub layer becomes less dominant and western juniper and grass increase in importance. Along a moisture gradient, Idaho fescue is found on moist sites, bluebunch wheatgrass on dry sites, and a mixture of these species on sites with intermediate moisture.

Characteristics of climax and seral stands of western juniper differ (Burkhardt and Tisdale 1969). Climax stands are found on the edges of mesas and ridges and rimrocks, where soil development is limited and fractured bedrock is near the surface. Western juniper roots may penetrate as deep as a meter into rock fractures, and thus, improve accessibility to stored moisture. Soils are interrupted by numerous rock outcrops, which may make up more than 50% of the ground surface. Parent material is often rhyolitic gravel. Vegetation of these climax sites is sparse and the surface may be covered by fine gravel pavement, making them less susceptible to fire. Climax communities of western juniper in Central Oregon are found on shallow, basaltic lava from geologically recent volcanic activity (Sowder and Mowat 1958).

Seral stands of western juniper occur on valley slopes and bottoms adjacent to old juniper stands (Burkhardt and Tisdale 1969). Soils are more uniform and deeper than those of climax stands, with few, if any, rock outcrops, although large boulders may be present. Parent material is usually rhyolitic alluvium.

Climax stands of western juniper contain trees from seedlings to several hundred years old, with most individuals in an intermediate age class; seral stands contain a many-aged population with a maximum age of nearly 100 years and most individuals in young age classes (Burkhardt and Tisdale 1969). Old stands have trees with round-topped crowns lacking strong terminal leaders, while invading stands are comprised of young trees with conical-shaped crowns and prominent terminal leaders.

A dramatic increase in establishment of western juniper in much of the Intermountain West seems to have occurred in the late 1800's and early 1900's (Burkhardt and Tisdale 1969, 1976, Adams 1975, Young and Evans 1981). Historically, fire may have prevented the spread of western juniper from its topo-edaphic climax communities on rock outcrops to valleys below them (Young and Evans 1981). In a study of western juniper in southwest Idaho, Burkhardt and Tisdale (1969, 1976) concluded cessation of periodic fires was directly related to western juniper expansion into sites originally dominated by mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) and perennial bunchgrasses. In the absence of fire, effective moisture appeared to determine distribution (Dealy et al. 1978b). Disturbance of the site by livestock has also been hypothesized as playing a role in the survival and thickening of western juniper stands established as a result of fire protection (Dealy et al. 1978a). Grazing has resulted in the reduction of fine fuels and a decrease in fire frequency. Range condition appears to have had little effect on western juniper expansion, since evidence suggests that competition from herbaceous plants has little or no repressive effect on juniper seedlings (Burkhardt and Tisdale 1976).

Fossil records show the recent advance of western juniper in eastern Oregon is not unique to the historic period of grazing by cattle, sheep, and horses, and reduced fire frequencies (Mehringer and

Wigand 1984). The rate and degree of changes in western juniper populations in the late Holocene were equal to or greater than those seen over the past 100 years. During the pluvial intervals of the Pleistocene epoch, much of the present area dominated by sagebrush was probably covered by pinyon and juniper (Mehringer 1977).

Although relatively little research has examined understory/overstory dynamics of western juniper communitites, these relationships have been explored in other communitites dominated by woody species. Expansion of pinyon (Pinus spp.) and juniper (Juniperus spp.) has affected associated herbaceous vegetation. Increased tree distribution and density effects have been documented for the pinyon-juniper type (Dwyer 1975). In general, invasion and growth of trees reduce the quantity and quality of available forage. The stage of community development characterized by an abundance of pinyon and juniper seedlings, saplings, and a few vigorous and mature trees appears to be the point where pinyon and juniper begin to exert their influence over the understory (Blackburn and Tueller 1970). Decline in pinyon-juniper establishment over the last 50 years may be due to the saturation of available sites by early tree establishment (Tausch et al. 1981).

Pinyon and juniper dominate associated vegetation because they can apparently support an equal biomass of live tissue on roughly one-eighth the resources of space, water, and nutrients needed by herbaceous vegetation (West et al. 1979). Tree size is an important factor. Understory associated with small trees in established stands reflects conditions existing prior to establishment of young trees. Trees begin to dominate the understory in 60 to 70 years, when they reach approximately one-third of their climax potential. Although height of trees at this point is only double that of shrubs, understory species decline at an increasingly rapid rate as trees begin to compete for soil moisture. Thus, as trees mature, the understory is reduced (Blackburn and Tueller 1970, West et al. 1979, Tausch et al. 1981). Also, seed reserves of important forage species decline and species diversity decreases as tree age and density increase (Koniak and Everett 1982).

Mechanisms by which individual trees affect invaded sites are yet undefined; many causal factors have been proposed. Distinct vegetation zones occurring within the understory of one seed juniper

(Juniperus monosperma) were attributed to soil moisture characteristics (Arnold 1964). Duff thickness was found to directly affect understory production in singleleaf pinyon (Pinus monophylla) - Utah juniper (Juniperus osteosperma) stands, (Everett and Koniak 1981). In another study, chemical composition of litter from Colorado pinyon (Pinus edulis) and Utah juniper was the major factor affecting basal area and production of understory grass species (Jameson 1966). Soil temperature, in relation to moisture characteristics, has also been examined and found to affect growth rate and production of some annual grasses which often occur associated with western juniper (Evans et al. 1970, Uresk et al. 1979). Light intensity is another factor that influences composition and production of understory plant species (Benedict 1941, Shirley 1945). In coniferous forests, studies of canopy openings as determinants of understory herb composition have found response may actually be more dependent upon throughfall precipitation than light levels (Anderson et al. 1969).

The presence of woody species has been shown to induce patterns of soil nutrients by affecting ion uptake and redistribution of ions in litter (Charley and West 1975). Surface concentrations of nutrients were greater under individual big sagebrush plants in comparison to interspace and grass-influenced soils (Doescher et al. 1984). Tiedemann and Klemmedson (1973) found nutrient concentrations in soils were greater under mesquite (Prosopis juliflora) than in open areas between trees. Production of understory native grasses showed species specific differences related to variation in soil nutrient concentrations. The development of soil nutrient patterns was also species specific. Concentrations of minerals in soils and plants were different between mountain mahogany (Cercocarpus montanus) and Utah juniper communities (Brotherson and Osayande 1980).

Once a tree is established, it affects the surrounding vegetation (Johnson 1962). Although there were no differences between understory and interspace in proportion of plant cover and plant cover/m^2 in a singleleaf pinyon- Utah juniper community, Everett and Koniak (1981) found annual forbs and perennial grasses made up a large portion of understory cover and varied greatly in production. Production of individual understory species varied with topographic aspect, slope position relative to the tree stem, and tree size (Everett et al. 1983). Understory cover was highest on north aspects, intermediate on west aspects, and lowest on south aspects. Species were individually affected by their position relative to the tree crown. Idaho fescue plants were most abundant on the north sides of trees, reflecting the beneficial shading effects of trees creating more mesic microsites. Unshaded south microsites appeared to exceed the moisture and temperature tolerance limits of even Sandberg bluegrass (Poa sandbergii).

Large trees have been shown to benefit understory production. Aboveground biomass of early spring grasses was 4 to 5 times greater under crowns of alligator juniper (Juniperus deppeanna) than for similar-sized areas away from trees (Clary and Morrison 1973). On many sites, cool season grasses were more abundant under large alligator juniper than in either natural openings or those created by juniper removal. Squirreltail (Sitanion hystrix), junegrass (Koeleria cristata), and western wheatgrass (Agropyron smithii) appear to benefit from the presence of large trees that create a cooler and more modulated temperature regime in the understory.

Understory cover showed a negative geometric reduction for each unit increase of cover of singleleaf pinyon and one-seed and Utah juniper

(Tausch and Tueller 1977). In general, as the overstory of pinyon and juniper increased, the amount of associated palatable species was reduced (Arnold et al. 1964, Blackburn and Tueller 1970, West et al. 1979, Tausch et al. 1981). Perennial grasses and perennial forbs declined with increasing canopy of Colorado pinyon and Utah juniper; annuals invaded bare areas if excess soil moisture and favorable temperatures occurred at the same time (Arnold et al. 1964). The extent of tree impact on understory vegetation also depended on soil texture (Johnson 1962). Bare areas beyond the canopy of one seed juniper were evident only after trees were 0.6-1.0 m (2-3 ft) or taller on light soils, and after trees were over 2 m (6 ft) tall on heavy soils.

The negative impact of western juniper on understory forage production has resulted in many efforts directed toward removal of western juniper trees. The response in forage production following western juniper removal has allowed increases in stocking rates of beef cattle from 50 to 300% (Bedell and Bunch 1978), making improvement of woodlands an important management consideration. Canopy removal in the singleleaf pinyon- Utah juniper type resulted in significant increases in understory production (Barney and Frischknecht 1974).

After killing of Colorado pinyon- Utah juniper by girdling, herbage production increased from 43 kg/ha (38 lb/A) to 3703 kg/ha (3303 lb/A), on average, the fourth, sixth, and eighth year after treatment (Clary and Jameson 1981). Average production after tree removal increased more than 10-fold for grasses, 6-fold for forbs, and more than 6-fold for total herbage. Even 25 years following one-seed and Utah juniper removal, production was greater on treated areas than on adjacent undisturbed woodland (Kruse et al. 1979). Studies in the Colorado pinyon-Utah juniper woodlands of the Southwest indicated response to tree removal was dependent upon annual precipitation and nutrient characteristics of soil prior to treatment (Clary and Jameson 1981), type of treatment (e.g. fire, chaining, herbicide application, etc.), tree canopies, and followup treatments (Arnold et al. 1964). When fire was used as a means of control, Everett and Ward (1984) found understory plant cover in singleleaf pinyon- Utah juniper communities reached only two-thirds of preburn conditions 5 years after treatment. They suggested succession after tree removal followed several pathways and early plant community development was a product of disturbance, species pool, and timing of disturbance. In central Utah, biomass of weedy annuals peaked 3 to 4 years after removal of singleleaf pinyon- Utah juniper with fire (Barney and Frischknecht 1974). The site was occupied by a grass-forb community within 10 years following fire. Shrubs were well-established 20 years after the fire and dominated the site in 30 years. Although tree seedlings began to appear on the site in 10 to 20 years, the presence and impact of trees were not significant until up to 50 years. At 70 to 80 years, the site was a woodland, with little understory cover.

After chaining of a singleleaf pinyon- Utah juniper stand, plant community development followed the same sequence as that observed by Barney and Frischknecht (1974) following fire, but occurred over a shorter time period (Tausch and Tueller 1977). Maximum cover and full occupancy by forbs occurred within approximately 2 years. Perennial bunchgrasses dominated in 3 to 4 years, and larger shrubs after at least 5 years. Site differences were determined to influence the rate, but not the pattern of succession. Work with western juniper in northern California showed annual species were still dominant 7 years after treatment (Evans and Young 1985).

Juniper encroachment rates seem to be somewhat affected by management, but invasion was found to occur if seed was present and site factors satisfactory for germination (Bunting 1985). Western juniper communities grazed by livestock are characterized by an increase in western juniper, big sagebrush, and cheatgrass; bitterbrush (*Purshia tridentata*) and perennial grasses decrease (Driscoll 1964a, Dealy et al. 1978a, 1978b). Range condition does not, however, affect western juniper establishment. Grazing only affects juniper growth rate by reducing the amount of fine fuel and, consequently, the frequency and intensity of fires. Grazing management alone, therefore, is not expected to keep out juniper seedlings, or to suppress their growth and effect on associated vegetation (Bedell and Bunch 1978). Reducing, or even eliminating grazing by livestock is not assumed to reverse the trend of invasion.

I. WESTERN JUNIPER EFFECTS ON ASSOCIATED UNDERSTORY SPECIES PRODUCTION, I. NATURAL STANDS.

INTRODUCTION

Western juniper (*Juniperus occidentalis* Hook., ssp. *occidentalis*) is a plant indigenous to much of the interior Pacific Northwest (Vasek 1966). Historically, western juniper was limited in distribution by fire (Driscoll 1964) and confined to rocky ridges. Understory production on these sites was sparse (Burkhardt and Tisdale 1969, 1976). Over the past 100 years, possibly as a result of fire suppression and overuse of rangelands by livestock, western juniper has expanded its range, principally into mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*)- perennial bunchgrass communitites.

The impact of invasion and establishment of trees on understory vegetation has been documented for pinyon-juniper communities of the western United States (Dwyer 1975). Junipers influence and modify plant associations under their canopies (Dealy et al. 1978, Everett et al. 1983). Frequency of many perennial grass and forb species has been found to decline as western juniper canopies increase in density. Forage seed reserves decline and species diversity decreases as tree age and density increase (Koniak and Everett 1982). Effects of tree expansion on understory production and composition may be dependent upon stage of stand development (Blackburn and Tueller 1970, West et al. 1979), tree size, topographic aspect, and slope position relative to the tree stem (Everett et al. 1983). Zonation of understory herbaceous vegetation around individual trees has been found for one-seed juniper (Juniperus monosperma) (Arnold 1964) and alligator juniper (Juniperus deppeana) (Clary and Morrison 1973) in Arizona. The development of bare areas is also common in one-seed juniper understories (Johnson 1962). Competition for space, water, and nutrients (West et al. 1979), impact of duff thickness (Everett and Koniak 1981), as well as litter chemical composition (Jameson 1966) have all been proposed as mechanisms by which trees affect understory species.

Observations of western juniper communities in central Oregon indicate spatial patterns of understory vegetation associated with individual trees may exist. This study was initiated to determine if understory spatial patterns were present and to describe these spatial patterns relative to the size of western juniper trees.

STUDY AREA AND METHODS

The study area was located 8.8 km (5.5 miles) southeast of Prineville in central Oregon (T15S, R17E, Sec. 18) on a gentle north, northwest-facing slope. Longterm precipitation in Prineville (elevation 868 m (2850 ft)), the nearest recording station, averages 25.4 cm (10 in) annually, 89% of which occurs from October to June (Figure 1).

The study area falls into the Juniper Zone described by Driscoll (1964). It is characterized by the dominance of western juniper and associated shrubby vegetation, most commonly Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*), mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*), and scatterred low sagebrush (*Artemisia arbuscula*). Native perennial grasses include Idaho fescue (*Festuca idahoensis*), bottlebrush squirreltail

(Sitanion hystrix), bearded bluebunch wheatgrass (Agropyron spicatum), and Sandberg bluegrass (Poa sandbergii). Cheatgrass brome (Bromus tectorum) and many annual and perennial forbs comprise the rest of the herbaceous component (Appendix 1). Mixed tree size classes (Burkhardt and Tisdale 1969), continuing recruitment of western juniper trees, the presence of locally isolated areas of vigorous bunchgrasses, and on-site soil characteristics indicate the site is at a mid-seral successional phase.

Two study sites were selected in this area, one at an elevation of approximately 1140 m (3740 ft) and the other at an elevation of 1220 m (4000 ft). Lower slope soils were relatively shallow, approximately 40.6 cm (16 in), mixed, mesic Lithic Haploxerolls. Upper slope soils were moderately deep, approximately 73.7 cm (29 in), frigid Pachic Argixerolls. Both soils were derived from basaltic parent materials. In the following discussion, the lower slope, shallow soil site will be referred to as the lower slope site, and the upper slope, moderately deep soil site will be the upper slope site.

On each site, 2000 m^2 paired plots containing trees of similar size and density were delineated. In these plots, trees were separated into

3 tree canopy diameter size classes, small, less than 3 m (9.8 ft), intermediate, 3-5 m (9.8-16 ft), and large, greater than 5 m (16 ft). In the fall of 1982, trees were hand-cut from one of the two paired plots. Individual species herbage production was measured during the summers of 1983 and 1984 by clipping vegetation to ground level in small sample plots on an individual tree basis from five trees within each size class. Transects radiating from the bole 45 degrees to the cardinal directions were established, extending at least 0.5 m (20 in) beyond the edge of the canopy. Sample plot size varied with tree size, sampling at least 10% of the quadrant defined by a transect (0.3 m^2 sample plots with large trees, 0.3 and 0.1 m^2 with intermediate trees, and 0.1 and 0.04 m^2 with small trees). Samples were separated into 2 zones; 1. the beneath canopy zone from the base of the tree to the edge of the canopy and 2. the interspace zone, consisting of the area between tree canopies. On-site precipitation was collected using standard U.S. Forest Service-type rain gages and measured monthly during the course of the study.

A split-split plot analysis of variance was used to analyze data. Main plots were treatments (natural stand, trees removed), years (1983, 1984), and tree sizes (small, intermediate, large). Subplots were zones (beneath canopy, interspace) and sub-subplots were transects (northeast, northwest, southwest, and southeast). Means were separated using Tukey's w-procedure at $P \leq 0.05$ (Steel and Torrie 1980). Data presented here will deal only with production in plots with trees present.

RESULTS

Climatic Conditions

In 1983 and 1984 precipitation at Prineville, Oregon was 44 and 21%, respectively, above the 30-year average (Figure I.1). Precipitation at the study area, measured with rain gages, was greater than precipitation reported at Prineville for both years of the study and the 30 year average. On-site precipitation was 35% greater in 1983 and 67% greater in 1984 than precipitation at Prineville. Upper and lower slope precipitation did not differ the two years of the study.

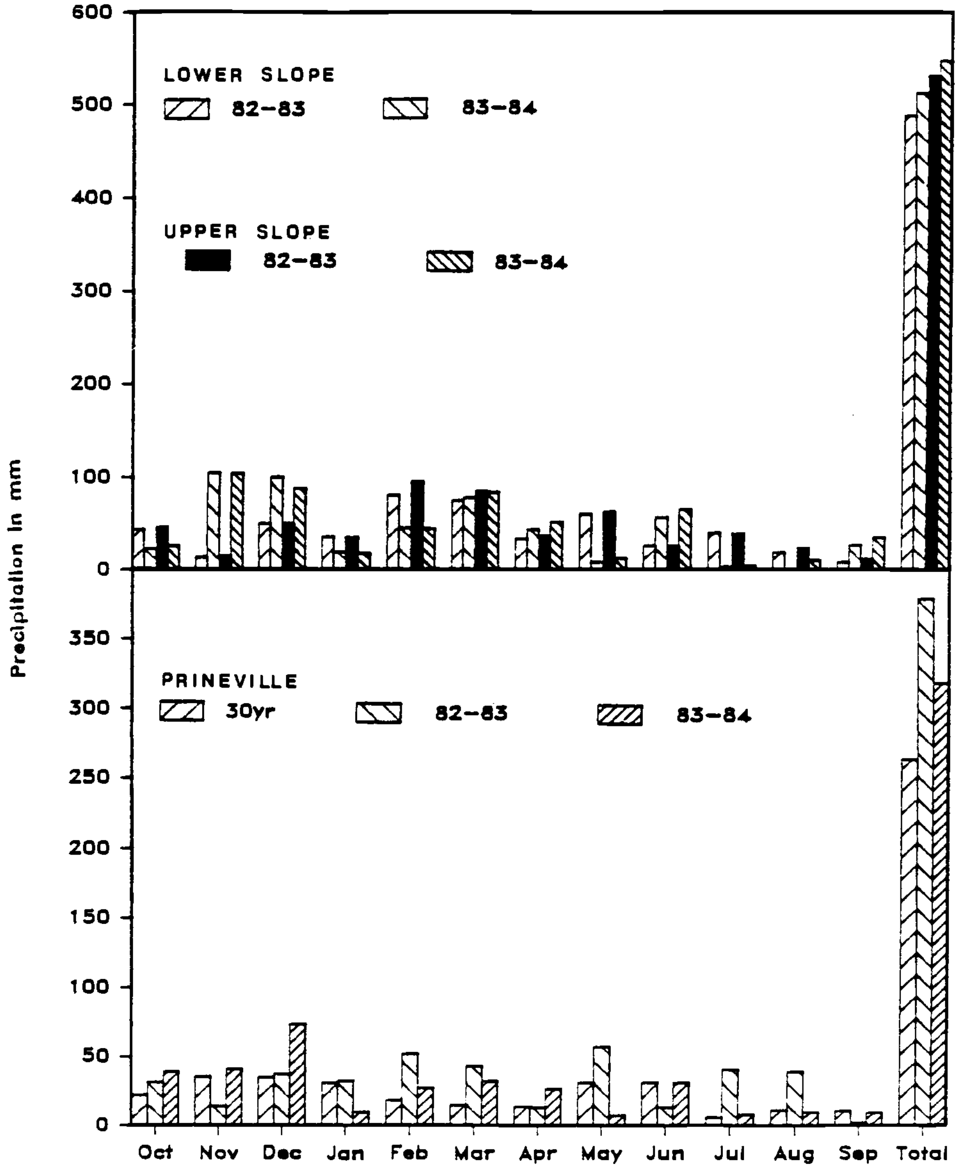

Figure I.1. Thirty year average and monthly average precipitation at Prineville, and monthly average precipitation at the study area.

Lower Slope

Total production in the lower slope, based on a 21% to 79% beneath canopy to interspace ratio was 41.48 g/m^2 (370 lb/A) in 1983 and 24.8 g/m^2 (221.3 lb/A) in 1984. Production varied with tree size and location.

Small Trees

The beneath canopy production of small trees was dominated by Sandberg bluegrass, squirreltail, cheatgrass, and annual forbs. Interspace production was dominated by Sandberg bluegrass, perennial forbs, annual forbs, and sagebrush. Total production beneath the canopy of small trees was greater in 1983 than 1984 (Table I.1).

Sandberg bluegrass, squirreltail, and cheatgrass production beneath the canopy was greater in 1983 than 1984. Total interspace production did not differ between years, but production of individual species showed differences. Sandberg bluegrass and annual forb production in the interspace was greater in 1983 than 1984, while sagebrush production in the interspace was greater in 1984 than 1983.

Table I.1. Mean herbage production on lower slope.

	Production in g/m²			
Zone	Beneath Canopy		Interspace	
Year	1983	1984	1983	1984
Tree Size Species				
Small Trees				
Sandberg bluegrass	11.14a1	5.05a2	22.60b1	7.84b2
Idaho fescue	0.00	0.00	0.00	0.00
Squirreltail	11.39a1	1.64 2	0.82b	0.03
Bluebunch wheatgrass	0.09	0.00	0.00	0.00
Cheatgrass	11.95a1	1.74 2	2.15b	2.15
Annual grasses	0.70	0.11	1.48	0.76
Perennial forbs	0.93	1.64	3.08	3.21
Annual forbs	9.37	3.97	11.78 1	4.75 2
Sagebrush	0.00	0.02	0.00 1	13.31 2
Total	45.56 1	14.18a2	41.90	32.05b
Intermediate Trees				
Sandberg bluegrass	10.25a1	4.12 2	17.42b1	6.23 2
Idaho fescue	0.00	0.00	0.00	0.00
Squirreltail	3.33	1.04	0.94	0.22
Bluebunch wheatgrass	3.38	0.98	0.21	0.10
Cheatgrass	9.40a	4.77	3.52b	0.03
Annual grasses	0.47	0.90	0.16	1.54
Perennial forbs	4.53	2.29	3.97	3.48
Annual forbs	5.96	4.23	8.52 1	2.76 2
Sagebrush	1.73	1.03	3.65	1.43
Total	39.04 1	19.35 2	38.39 1	15.74 2
Large Trees				
Sandberg bluegrass	9.74a	7.47a	19.02b1	10.26b2
Idaho fescue	0.00	0.00	0.00	0.00
Squirreltail	8.98a1	3.22 2	0.95b	0.36
Bluebunch wheatgrass	0.94	0.19	0.12	0.00
Cheatgrass	17.50a	12.75a	0.75b	0.11b
Annual grasses	1.16a	1.50	6.64b	3.32
Perennial forbs	4.80	5.26	5.61	5.31
Annual forbs	6.23	6.84	5.87	3.82
Sagebrush	3.52	1.13	1.76	3.84
Total	52.86a	38.36a	40.71b	27.27b

[1]Letters denote significant (α =0.05) differences between beneath canopy and interspace zones within species and years; numbers denote significant (α =0.05) differences between years within zones and species, using Tukey's w-procedure.
[2]Total production does not reflect the sum of individual categories. Miscellaneous species comprise the remainder of total production.

Total production did not differ between beneath canopy and interspace zones in 1983. Individual species did, however, show some differences. Sandberg bluegrass production was greater in the interspace than beneath the canopy; squirreltail and cheatgrass production was greater beneath the canopy than in the interspace in 1983. In 1984, total production was greater in the interspace than beneath the canopy, largely due to greater interspace than beneath canopy production of Sandberg bluegrass and sagebrush.

Total production beneath the canopy and in the interspace of small trees did not differ among directions, although there were individual species differences. Squirreltail beneath canopy production in 1983 was greater in the southeast, 21.70 g/m^2 (194 lb/A), than in the southwest, 4.19 g/m^2 (37 lb/A). Annual grass production tended to be greater in the northeast and southeast than in the northwest and southwest beneath the canopy and in the interspace in 1983. Interspace production of Sandberg bluegrass was greater in the northeast, 27.14 g/m^2 (242 lb/A), than in the northwest, 14.22 g/m^2 (127 lb/A), in 1983. Sagebrush interspace production was greater in the northwest, 25.58 g/m^2 (228 lb/A), and southeast, 26.48 g/m^2 (236 lb/A), than in the northeast, 1.16 g/m^2 (10 lb/A), and southwest, 0 g/m^2 (0 lb/A) in 1984 (Appendix 2).

Intermediate Trees

Production beneath the canopy of intermediate trees was dominated by Sandberg bluegrass, cheatgrass, perennial forbs, and annual forbs. Interspace production was dominated by Sandberg bluegrass and annual forbs. Total beneath canopy production was greater in 1983 than in 1984, primarily due to variation in Sandberg bluegrass production (Table I.1). Sandberg bluegrass and annual forbs in the interspace contributed more to total production in the interspace in 1983 than in 1984.

Total beneath canopy production did not differ from total interspace production, although there were some individual species differences. Sandberg bluegrass production was greater in the interspace than beneath the canopy in 1983; cheatgrass production was greater beneath the canopy than in the the interspace in 1983.

There were no significant differences in total production or individual species production based on direction either beneath the canopy or in the interspace (Appendix 2). Beneath canopy production of perennial grasses, such as squirreltail and bluebunch wheatgrass, however, tended to be greater in the northeast and southeast than in other directions in 1983, and in the southeast than other directions in 1984. Annual grass production tended to be greater in the southeast than in other directions both beneath the canopy and in the interspace both years.

Large Trees

Production beneath the canopy of large trees was dominated by Sandberg bluegrass, squirreltail, cheatgrass, perennial forbs, and annual forbs. Interspace production was dominated by Sandberg bluegrass, annual grasses, perennial forbs, and annual forbs. Total beneath canopy production did not differ from year-to-year, although squirreltail production beneath the canopy was greater in 1983 than 1984 (Table I.1). In the interspace, total production did not differ from year-to-year, although Sandberg bluegrass production was greater in 1983 than 1984.

Total beneath canopy production was greater than total interspace production both years, primarily due to squirreltail and cheatgrass. In 1983, squirreltail and cheatgrass beneath canopy production was greater than interspace production. In 1984, only cheatgrass beneath canopy production was greater than interspace production. Sandberg bluegrass and annual grass production in the interspace was greater than production beneath the canopy in 1983. Only Sandberg bluegrass production was greater in the interspace than beneath the canopy in 1984.

Total production beneath the canopy showed no differences with direction, although production of individual species did differ. Perennial grass production beneath the canopy tended to be greater in the southeast than other directions. Squirreltail production beneath the canopy was greater in the southeast, 21.19 g/m^2 (189 lb/A), than in any other direction in 1983. Annual grass production in the interspace was greater in the northwest, 18.24 g/m^2 (163 lb/A), than any other direction in 1983. Cheatgrass beneath canopy production was greater in the northeast, 31.49 g/m^2 (74 lb/A), than in the southeast, 8.30 g/m^2 (74 lb/A), in 1983 (Appendix 2).

Comparison of Tree Size

There were no tree size-dependent trends in total beneath canopy production in 1983. In 1984, however, total production beneath the canopy was greater with increased tree size, a trend also evident in beneath canopy cheatgrass production (Figure I.2). In the interspace zone, only sagebrush production showed any tree size dependent trends. Production of sagebrush in the interspace was inversely related to increase in tree size.

Upper Slope

Total production on the upper slope, based on a 40% to 60% beneath canopy to interspace ratio was 49.7 g/m^2 (442 lb/A) in 1983 and 42.2 g/m^2 (376 lb/A) in 1984. There were tree size dependent and location-specific responses.

Small trees

Production beneath the canopy of small trees was dominated by Sandberg bluegrass and Idaho fescue. Interspace production was dominated by Sandberg bluegrass, Idaho fescue, and annual forbs. Total production did not differ between years beneath the canopy or in the interspace associated with small trees (Table I.2). Most species did not differ from year to year. Only Sandberg bluegrass production, as

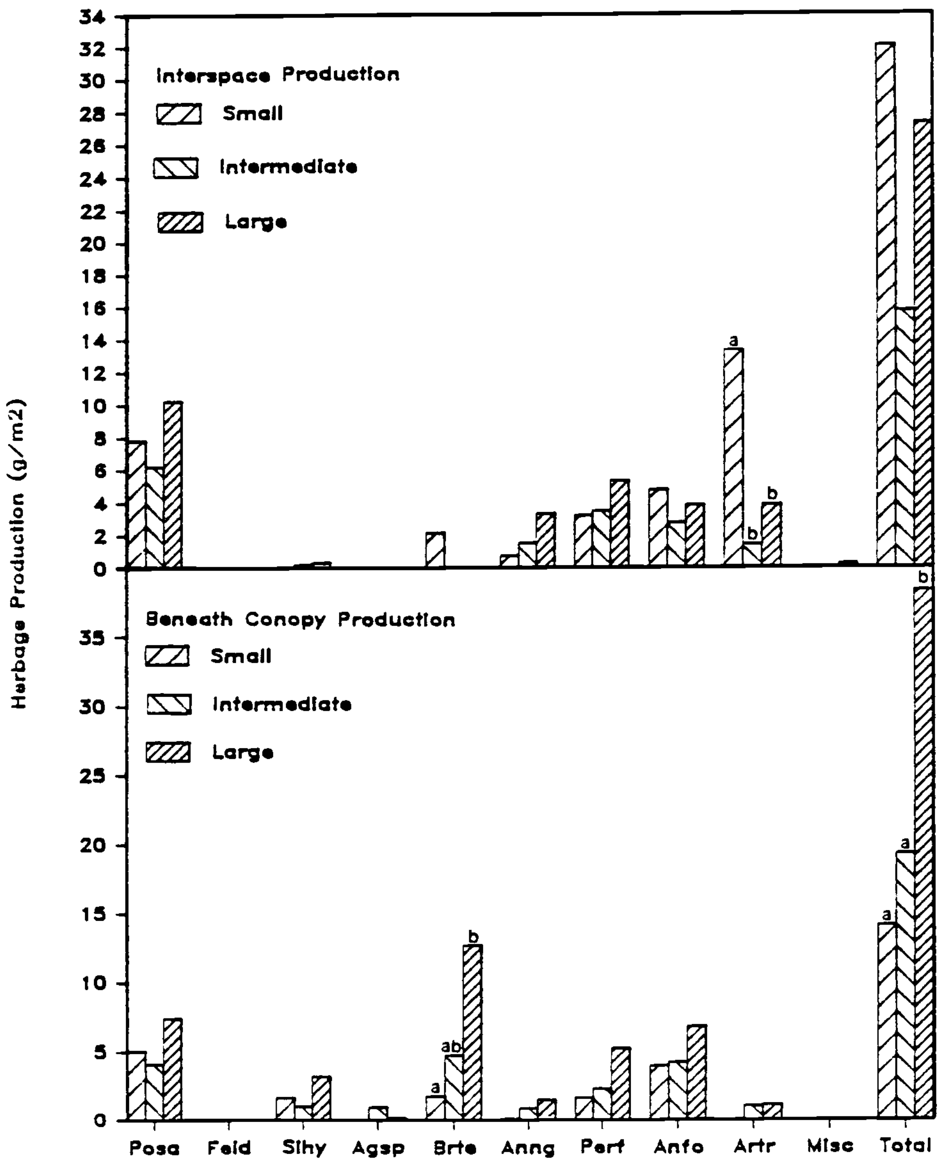

Figure I.2. 1984 herbage production on the lower slope. (Posa- Poa sandbergii, Feid- Festuca idahoensis, Sihy- Sitanion hystrix, Agsp- Agropyron spicatum, Brte- Bromus tectorum, Anng- Annual grasses, Perf- Perennial forbs, Anfo- Annual forbs, Artr- Artemisia tridentata, Misc- Miscellaneous) Different letters denote significant (α=0.05) differences between tree size production values within species, using Tukey's w-procedure.

Table I.2. Mean herbage production on upper slope.

	Production in g/m²			
Zone	Beneath Canopy		Interspace	
Year	1983	1984	1983	1984
<u>Tree Size</u>				
Species				
<u>Small Trees</u>				
Sandberg bluegrass	10.36a1	5.05 2	16.35b1	8.28 2
Idaho fescue	22.74a	15.86a	8.86b	3.19b
Squirreltail	4.41	0.59	1.09	0.50
Bluebunch wheatgrass	0.89	1.29	2.07	1.24
Cheatgrass	0.38	0.05	0.03	0.02
Annual grasses	0.00	0.01	0.02	0.77
Perennial forbs	5.07	3.90	1.69	0.73
Annual forbs	0.65	5.17	1.73	8.38
Sagebrush	2.81	4.15	4.28	11.45
Total	48.11	36.07	36.52	34.54
<u>Intermediate Trees</u>				
Sandberg bluegrass	9.37a1	3.89 2	15.68b1	7.09 2
Idaho fescue	8.73	1.68	7.29	4.22
Squirreltail	2.90	1.95	2.40	0.87
Bluebunch wheatgrass	1.24	0.42	1.39	1.22
Cheatgrass	5.63	7.65	2.28 1	11.65 2
Annual grasses	0.05	0.20	0.25	1.51
Perennial forbs	12.81	16.63a	5.06	6.39b
Annual forbs	6.07	4.64	7.05	12.18
Sagebrush	2.00	3.57	6.66	3.04
Total	48.82	40.62	48.07	38.16
<u>Large Trees</u>				
Sandberg bluegrass	4.96a	1.91	12.93b2	5.16 2
Idaho fescue	8.47	6.61	8.15	6.26
Squirreltail	4.33	5.29	2.43	0.82
Bluebunch wheatgrass	0.79	1.21	1.39	0.63
Cheatgrass	7.43	11.26a	3.56	1.18b
Annual grasses	1.33	1.44	1.67	4.78
Perennial forbs	22.08a	25.55a	11.83b	9.88b
Annual forbs	3.36	4.85	6.65	12.08
Sagebrush	3.20a	3.98	12.73b	4.36
Total	56.45	62.59	61.44	45.44

[1] Letters denote significant (α =0.05) differences between beneath canopy and interspace zones within species and years; numbers denote significant (α =0.05) differences between years within zones and species, using Tukey's w-procedure.

[2] Total production does not reflect the sum of the individual categories. Miscellaneous species comprise the remainder of total production.

on the lower slope, was greater in 1983 than 1984 both beneath the canopy and in the interspaces.

Total production associated with small canopies did not differ between beneath canopy and interspace zones. Production of some species, however, showed differences. Production of Sandberg bluegrass was greater in the interspace than beneath the canopy in 1983 and Idaho fescue production was greater beneath the canopy than in the interspace both years.

Total beneath canopy production did not differ among directions, but individual species production was variable. Perennial grass production beneath the canopy tended to be greater in the northwest than in any other direction. In 1983, Idaho fescue production beneath the canopy was greater in the northwest, 34.17 g/m^2 (216 lb/A), and southwest, 31.86 g/m^2 (284 lb/A), than in the southeast, 9.16 g/m^2 (80 lb/A). In 1984, Idaho fescue production beneath the canopy in the northwest, 26.97 g/m^2 (241 lb/A), was greater than production in the northeast, 6.24 g/m^2 (56 lb/A). Sandberg bluegrass production beneath the canopy was greater in the southwest, 11.97 g/m^2 (107 lb/A) and southeast, 16.81 g/m2 (150 lb/A), than in the northwest, 1.37 g/m^2 (12 lb/A), in 1983. Total interspace production showed no differences, but Sandberg bluegrass production was greater in the northwest, 19.66 g/m^2 175 lb/A), and southwest, 21.12 g/m^2 (188 lb/A), than in the northeast, 7.51 g/m^2 (67 lb/A), in 1983. Perennial grass production in the interspace tended to be greater in the northeast and southeast than in the northwest and southwest. Sagebrush interspace production was greater in the southwest, 23.20 g/m^2 (207 lb/A), than in the northeast, 0 g/m^2 (0 lb/A) in 1984 (Appendix 3).

Intermediate trees

Production beneath the canopy of intermediate trees was dominated by Sandberg bluegrass, Idaho fescue, and perennial forbs. Sandberg bluegrass, Idaho fescue, perennial forbs, and annual forbs dominated interspace production. Total production associated with intermediate trees showed no year-to-year differences between beneath canopy or interspace zones. Similar to small trees, only Sandberg bluegrass beneath canopy and interspace production was greater in 1983 than 1984. Cheatgrass interspace production was greater in 1984 than 1983.

Although total production did not differ between beneath canopy and interspace zones, individual species production was variable. Sandberg bluegrass production, as with small trees, was greater in the interspace than beneath the canopy in 1983. Perennial forb production was greater beneath the canopy than in the interspace in 1984.

Total production did not differ among directions. However, Sandberg bluegrass production beneath the canopy was greater in the southeast, 15.74 g/m^2 (140 lb/A), than in the northwest, 3.18 g/m^2 (28 lb/A) (Appendix 3).

Large trees

Idaho fescue, cheatgrass, and perennial forbs dominated production beneath the canopy of large trees. In the interspace, Sandberg bluegrass, perennial forb, and sagebrush production was dominant. Total production beneath the canopy and in the interspace associated with large trees did not differ between years. As shown for small and intermediate trees, Sandberg bluegrass production in the interspace was greater in 1983 than 1984.

Although total production did not differ between beneath canopy and interspace, individual species showed location-dependent production. Sandberg bluegrass and sagebrush production was greater in the interspace than beneath the canopy in 1983. Cheatgrass and perennial forb production was greater beneath the canopy than in the interspace in 1984 and both years, respectively.

Total and individual species production beneath the canopy was not different among directions both years. Production of perennial grasses beneath the canopy tended to be lower in the southwest than in other directions. In the interspace, however, total production in the northeast, 88.58 g/m^2 (790 lb/A), was greater than production in the southwest, 37.68 g/m^2 (396 lb/A), in 1983, primarily due to greater perennial forb production in the northeast, 37.68 g/m^2 (336 lb/A), than in the northwest, 2.47 g/m^2 (22 lb/A), southwest, 2.70 g/m^2 (24 lb/A), and southeast, 4.48 g/m^2 (40 lb/A). Perennial grass production in the interspace tended to be greater in the northeast and northwest than in the southeast and southwest. Sagebrush interspace production in 1983 was greater in the southeast, 33.45 g/m^2 (298 lb/A), than in all other directions (Appendix 3).

Comparison of Tree Sizes

As on the lower slope, tree size influenced production. Total production beneath the canopy on the upper slope showed trends toward greater production with increased canopy size, especially in 1984 (Figure I.3). In 1984, total production beneath the canopy of large trees was greater than total production beneath intermediate and small trees. Individual species trends were variable. Beneath canopy production of cheatgrass and perennial forbs showed a trend toward greater production with increase in tree size. Cheatgrass and perennial forb production beneath the canopy of large trees was greater than production beneath small trees both years; production beneath the canopy of intermediate trees was greater than production beneath small trees only in 1984. Idaho fescue production beneath the canopy was inversely related to tree size. Production of Idaho fescue was greater beneath the canopy of small trees than beneath intermediate and large trees both years. Although other species showed general trends, they were not significant.

In 1983, interspace production associated with large trees was greater than interspace production associated with small trees. In 1984, total interspace production tended to be greater as tree size increased (Figure I.3). Production of perennial forbs, annual forbs, and annual grasses tended to be

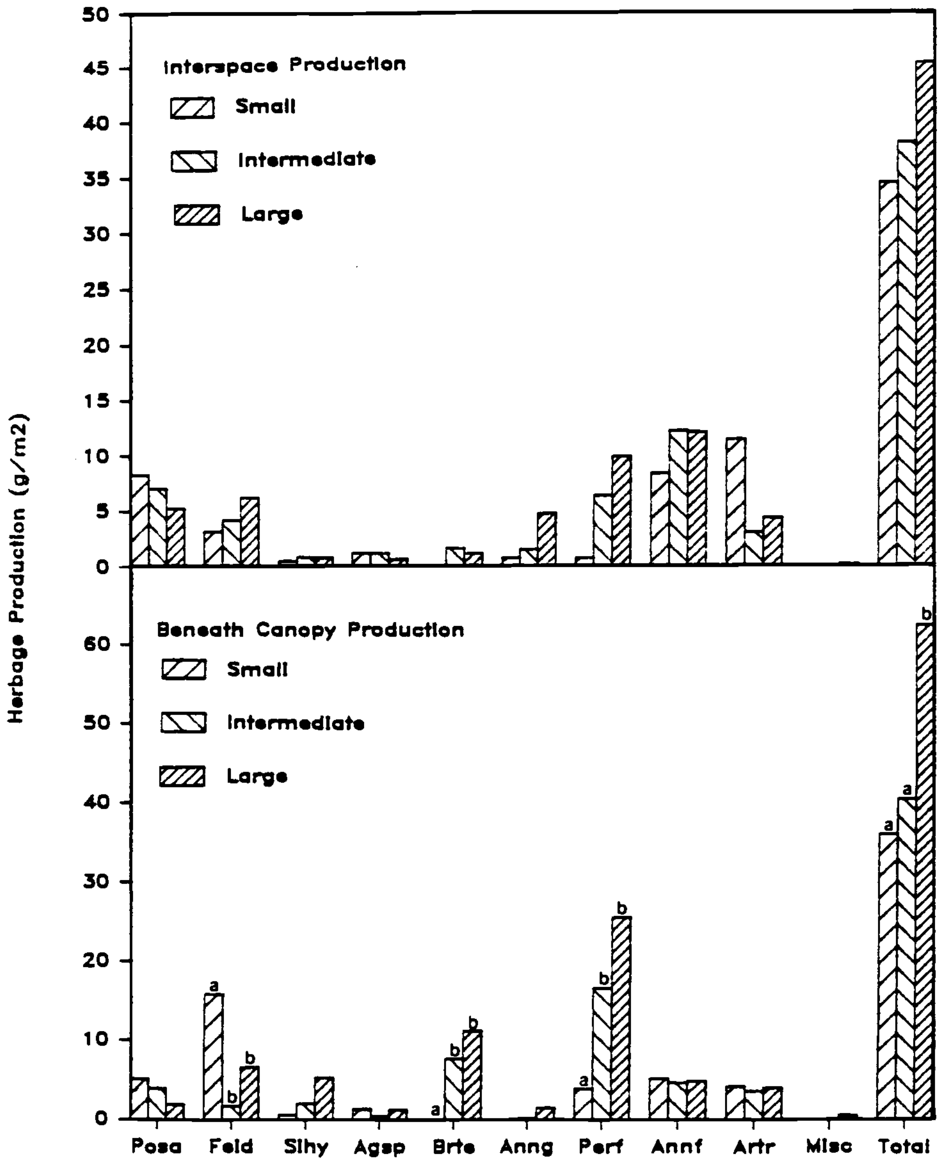

Figure I.3. 1984 herbage production on the upper slope. (Posa- Poa sandbergii, Feid- Festuca idahoensis, Sihy- Sitanion hystrix, Agsp- Agropyron spicatum, Brte- Bromus tectorum, Anng- Annual grasses, Perf- Perennial forbs, Annf- Annual forbs, Artr- Artemisia tridentata, Misc- Miscellaneous) Different letters denote significant ($\alpha = 0.05$) differences between tree size production values within species, using Tukey's w-procedure.

greater in interspaces associated with intermediate and large trees than small trees both years.

DISCUSSION AND CONCLUSIONS

Growing season precipitation patterns during the study, in combination with tree size effects may partially explain variation in production of vegetation associated with western juniper trees. The difference in growing season precipitation probably has the greatest impact on vegetation associated with small trees. At this size, the tree does not exert a great physical influence on the surrounding environment. As the tree size increases, however, the beneath canopy microenvironment changes. Light penetration, temperature, and evaporation under the canopy are all affected. The canopy acts to ameliorate moisture fluctuations in the understory and, thus, compensates for vagaries in precipitation. Conversely, the interspace environment is not influenced as greatly by the above-ground physical features of the tree and climate exerts greater influence upon associated vegetation. Year-to-year differences in production of individual species relative to specific tree sizes may be explained by variation in precipitation during critical growth periods over the two years of this study. May precipitation in 1983 was approximately 6 times greater than May precipitation in 1984 (Figure 1). Although June precipitation in 1984 was more than twice as great as June precipitation in 1983, it may have occurred too late to compensate for the lower precipitation for May in 1984, resulting in decreased production of some species. Sandberg bluegrass and, possibly, Idaho fescue production may be sensitive to late spring precipitation and, thus, production in 1984 was lower than production in 1983.

Physical features of the study area may explain composition differences. Herbaceous species are distributed along both major environmental gradients of topography, moisture, or elevation (Bell 1974), and microenvironmental gradients resulting from microtopographical differences, structure of overstory, or temporal changes (Bratton 1976). Differences in species composition between the upper and lower slope may be traced to soil depth and its effect on soil moisture. The shallow soils of the lower slope supported more squirreltail and cheatgrass. The moderately deep soils of the upper slope supported a greater amount of Idaho fescue and perennial forbs. Annual forb production was apparently not influenced by soil depth. Total production of all species tended to be greater on the upper slope than on the lower slope.

West et al. (1979), working in singleleaf pinyon (Pinus monophylla) - Utah juniper (Juniperus osteosperma) woodlands found tree size affected the production of associated species. The influence of western juniper on associated species in this study was apparently also tree size-related. Cheatgrass and perennial forb production beneath the canopy was greater with increase in tree size, while the production of other species, such as Sandberg bluegrass, was apparently not affected by tree size. Everett et al. (1983) found similar species-specific responses to tree size in singleleaf pinyon- Utah juniper communities.

Understory species abundance was related to tolerance of moisture stress. Cheatgrass and Idaho fescue production was greater along north rather than south transects beneath individual large trees. Sagebrush interspace production was greater along south transects, regardless of canopy size. Squirreltail production was greater along south than north transects only in the interspace of large trees.

Species-specific patterns developed in the production beneath the canopy and in the interspace. The cooler and more moist conditions and, possibly, greater nutrient concentrations beneath the canopy favored production of Idaho fescue, squirreltail, cheatgrass, and perennial forbs. Sandberg bluegrass, annual forb, and sagebrush production was greater in the warmer and drier interspace. These production patterns were most clearly developed associated with large trees.

The results of this study indicate the significant role microenvironments play in species distribution and production in western juniper stands. Individual trees have a great influence on associated vegetation. Examination of both physical and chemical properties is warranted to understand exactly how western juniper impacts understory herbage composition and production.

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II. WESTERN JUNIPER EFFECTS ON ASSOCIATED UNDERSTORY SPECIES PRODUCTION II. TREES REMOVED

INTRODUCTION

Distribution and density of western juniper (*Juniperus occidentalis* Hook. ssp. *occidentalis*) (Vasek 1966) have increased on many Intermountain rangelands over the past 100 years (Burkhardt and Tisdale 1969, 1976). Overgrazing, fire suppression, and climatic change have all been implicated as possible factors contributing to western juniper expansion. Stands are best developed and highly concentrated in central and south-central Oregon (Dealy et al. 1978)

Western juniper can alter understory composition, affect soil properties under its crown (Dealy et al 1978), and has been cited as a direct cause of decline in palatable forb and grass production, especially in mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*)- perennial bunchgrass communities (Bedell and Bunch 1978, Burkhardt and Tisdale 1976).

Studies in pinyon-juniper (Pinus monophylla-Juniperus osteosperma) communities have demonstrated understory species composition and distribution change as trees increase in size (Everett et al. 1983). The overstory of pinyon and juniper tends to reduce the amount of associated understory species (Arnold et al. 1964, Tausch and Tueller 1977, West et al. 1979). With increasing canopy size comes a decline in cover of perennial grasses and perennial forbs, and an increase of annuals under juniper. Blackburn and Tueller (1970) showed pinyon and juniper trees reduce production and vigor of understory species when the stand reaches a specific stage of development, characterized by abundant seedlings, small saplings, saplings, and a few mature and vigorous old trees.

Improvement of ranges invaded by pinyon-juniper has involved fire, mechanical removal, and individual tree harvest. Significant increases in understory production may result from canopy removal (Barney and Frischknecht 1974). Production increased more than 10-fold for grasses and 6-fold for total herbage production (Clary and Jameson 1981), and lasted as long as 25 years after treatment (Kruse et al. 1979). Release of soil moisture formerly utilized by overstory species, and release of nutrients have been proposed as reasons for the flush of growth of associated species following tree removal (Evans and Young 1985).

Few studies have explored overstory and understory relationships and responses to tree removal in western juniper woodlands. Response has been assumed to be similar to that observed for pinyon-juniper forests. Recent studies show these assumptions may not be accurate (Evans and Young 1985). This study, therefore, was initiated to examine the response in production and composition of understory species with tree removal and the relationship of that response to tree size.

STUDY AREA AND METHODS

The study area was located 8.8 km (5.5 miles) southeast of Prineville in central Oregon (T15S, R17E, Sec.18) on a gentle north, northwest-facing slope. Longterm precipitation in Prineville, elevation 868 m (2850 ft), the nearest recording station, averages 254 mm (10 in) annually, 89% of which occurs from October to June.

The study area falls into the Juniper Zone described by Driscoll (1964). It is characterized by the dominance of western juniper and associated shrubby vegetation, most commonly Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) and mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) and scattered low sagebrush (*Artemisia arbuscula*). Native perennial grasses include Idaho fescue (*Festuca idahoensis*), squirreltail (*Sitanion hystrix*), bluebunch wheatgrass (*Agropyron spicatum*), and Sandberg bluegrass (*Poa sandbergii*). Cheatgrass (*Bromus tectorum*) and many other annual and perennial forb species comprise the remainder of the herbaceous component (Appendix 1). Mixed tree size classes (Burkhardt and Tisdale 1969), continuing recruitment of western juniper trees, locally isolated areas of vigorous bunchgrasses, and on-site soil characteristics indicate the site is at a mid-seral successional phase.

Two study sites were selected along a slope, one at an elevation of 1140 m (3740 ft) and the other at an elevation of 1220 m (4000 ft). Lower slope soils were relatively shallow, 40.64 cm (16 in), mixed, mesic Lithic Haploxerolls. Soils on the upper slope were moderately deep, 73.66 cm (29.00 in), frigid Pachic Argixerolls. Both were derived from basaltic parent materials. In the following discussion, the site at lower elevation with shallow soils will be referred to as the lower slope and the higher elevation moderately deep soil site will be the upper slope.

On each site 2000 m^2 paired plots containing trees of similar size and density were delineated. In these plots, trees were separated into 3 canopy diameter size classes, small, less than 3 m (9.8 ft), intermediate, 3-5 m (9.8-16 ft), and large, greater than 5 m (16 ft). Trees were hand-cut from one of the two paired plots in the fall of 1982 and slash removed from the plot. Herbage production was measured on both plots during the summers of 1983 and 1984 on an individual tree basis from five trees within each size class. Vegetation was sampled along transects established 45 degrees to the cardinal directions, radiating from the bole of each individual sample tree and extending at least 0.5 m (20 in) beyond the edge of the canopy. Sample plot size varied with tree size, sampling at least 10% of the quadrant defined by a transect (0.3 m^2 sample plots with large trees, 0.3

and 0.1 m^2 plots with intermediate trees, and 0.04 m^2 plots with small trees). Samples were separated into two zones: 1. beneath canopy zone from the base of the tree to the edge of the canopy, and; 2. interspace zone from the area between tree canopies. Vegetation was clipped from the small plots, oven-dried, and weighed. On-site precipitation was collected using a standard U.S. Forest Service-type rain gage and measured monthly during the two years of the study.

A split-split plot analysis of variance was used to analyze data. Main plots were treatment (tree present, tree removed), years (1983, 1984), and tree size (small, intermediate, large). Subplots were zones (beneath canopy, interspace) and sub-subplots were transects (45 degrees to cardinal directions). Means were separated using Tukey's w-procedure at $P \leq 0.05$ (Steel and Torrie 1980). Results presented here are a composite of trees sampled within each tree size class.

RESULTS

Climatic Conditions

In 1983 and 1984 precipitation at Prineville, Oregon was 44 and 21%, respectively, above the 30 year average (Fig.II.1). Precipitation at the study area, measured with rain gages, was greater than precipitation reported at Prineville. On-site precipitation from October to June was 420 mm (16.53 in) and 480 mm (18.90 in) on the lower slope and 454 mm (17.88 in) and 494 mm (19.47 in) on the upper slope for 1983 and 1984, respectively. This compares to 235 mm (9.25 in) for the 30-year October to June average at Prineville.

Lower Slope

Trees Present

Total production on the lower slope with trees present, based on a 21% to 79% beneath canopy to interspace ratio, was 41.48 g/m^2 (370 lb/A) in 1983 and 24.81 g/m^2 (221.3 lb/A) in 1984. dividual species production varied with location and tree size.

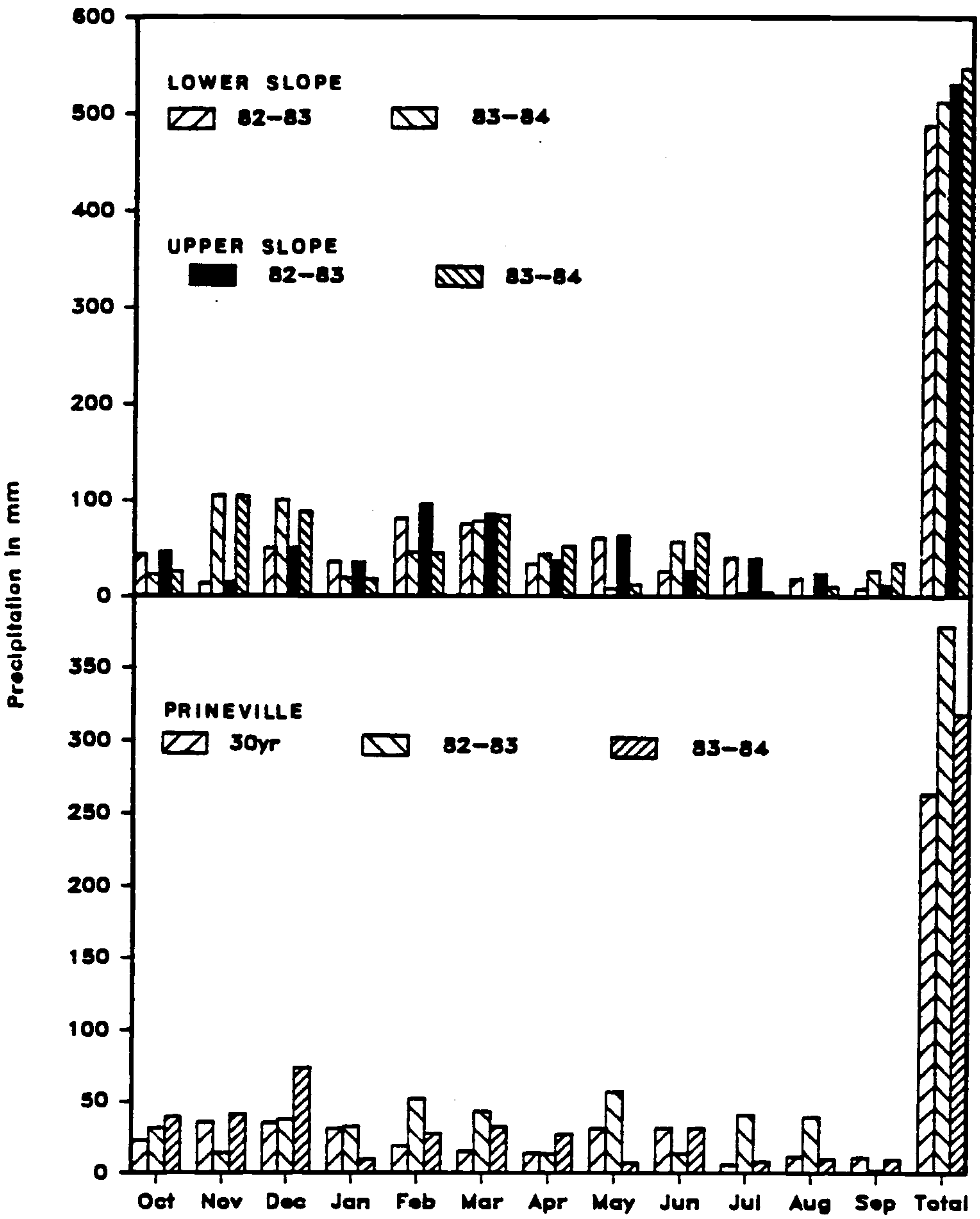

Figure II.1. Thirty year average and monthly average precipitation at Prineville, and monthly average precipitation at the study area.

Trees Removed

Total production on the lower slope with trees removed, based on a 21% to 79% beneath canopy to interspace ratio, was estimated at 67.88 g/m^2 (606 lb/A) the first year following tree removal and 72.17 g/m^2 (644 lb/A) the second year. Sandberg bluegrass, squirreltail, cheatgrass, perennial forbs, and annual forbs dominated beneath canopy production. Interspace production was dominated by Sandberg bluegrass, annual grasses, perennial forbs, and annual forbs.

Total production beneath the canopy of intermediate and large trees was greater in 1984 than 1983 (Table II.1). Individual species production was location and tree-size dependent, with a strong trend for greater production in 1984. Cheatgrass production was greater in 1984 than 1983 associated with intermediate and large trees and contributed to total production differences between years beneath the canopy. Production tended to be greater in 1984 than 1983 for squirreltail beneath the canopy of small and large trees, and for perennial forbs beneath small trees. Sandberg bluegrass and bluebunch wheatgrass production was lower in 1984 than 1983 beneath the canopy of small trees.

Table II.1. Mean herbage production on lower slope.

		Beneath Canopy Production in g/m2			
Year		1983		1984	
Canopy Status		Removed	Present	Removed	Present
Species	Tree Size				
Sandberg bluegrass					
	Small	14.84a	11.14a	9.95b	5.05b*
	Interm	7.58	10.25a	6.64	4.12b
	Large	9.00	9.74	8.11	7.47
Idaho fescue					
	Small	0.00	0.00	0.00	0.00
	Interm	0.00	0.00	0.00	0.00
	Large	0.34	0.00	0.10	0.00
Squirreltail					
	Small	8.31a	11.39a	19.31b	1.64b**
	Interm	6.67	3.33	7.95	1.04 *
	Large	11.70a	8.98a	19.74b	3.22b**
Bluebunch wheatgrass					
	Small	9.31a	0.09 **	0.18b	0.00
	Interm	2.16	3.38	4.83	0.98
	Large	2.71	0.94	5.83	0.19
Cheatgrass					
	Small	9.81	11.95a	8.49	1.75b
	Interm	16.14a	9.40	29.04b	4.77 **
	Large	42.85a	17.50 **	53.56b	12.75 **
Annual grasses					
	Small	0.02	0.70	0.06	0.11
	Interm	3.35	0.47	6.32	0.90 *
	Large	1.99	1.16	5.50	1.50
Perennial forbs					
	Small	6.79a	0.93	15.69b	1.64 **
	Interm	8.83	4.43	16.02	2.29 **
	Large	2.34	4.80	8.46	5.26
Annual forbs					
	Small	21.84	9.37 **	23.43	3.97 **
	Interm	24.62	5.96 **	26.55	4.23 **
	Large	17.88	6.23 **	13.69	6.84 *
Sagebrush					
	Small	0.01	0.00	1.90	0.02
	Interm	0.13	1.73	1.11	1.03
	Large	3.12	3.52	2.26	1.13
Total					
	Small	70.91	45.56a**	70.02	14.18b**
	Interm	69.49a	39.04a**	98.45b	19.35b**
	Large	91.93a	52.86 **	116.80b	38.36 **

[1]Letters denote significant (α =0.05) differences between years within tree sizes and treatments; * denote significance (* =0.05, ** =0.01) differences between tree present and tree removed areas, using Tukey's w-procedure.
[2]Total production does not reflect the sum of all categories. Miscellaneous species comprise the remainder of total production.

Total interspace production did not differ between years, although individual species did show location and tree size-dependent relationships (Table II.2). Interspace production of Sandberg bluegrass was greater in 1983 than 1984 regardless of tree size. Bluebunch wheatgrass interspace production associated with small trees was greater in 1984 than 1983, as was production of annual grasses in the interspace of large trees. Annual forb production in the interspace of small trees was greater in 1983 than 1984.

With trees removed, differences between beneath canopy and interspace production among species and between tree sizes occurred in specific patterns. Production trends which occurred with trees present were accentuated when trees were removed. In 1983, total beneath canopy production, 91.93 g/m^2 (829 lb/A), was greater than total interspace production, 64.83 g/m^2 (578 lb/A), associated with large trees. In 1984, total production associated with all tree sizes tended to be greater beneath the canopy than in the interspace, although the differences were only significant for intermediate and large trees.

Beneath canopy cheatgrass and squirreltail production was greater than interspace production both years with most tree sizes. Only cheatgrass production

Table II.2. Mean herbage production on lower slope.

		Interspace Production in g/m[2]			
Year		1983		1984	
Canopy Status		Removed	Present	Removed	Present
Species	Tree Size				
Sandberg bluegrass					
	Small	19.12a	22.60a	13.32b	7.84b*
	Interm	18.44a	17.42a	11.17b	6.23b*
	Large	19.50a	19.02a	11.07b	10.26b
Idaho fescue					
	Small	0.00a	0.00	2.71b	0.00 **
	Interm	0.00	0.00	0.00	0.00
	Large	0.00	0.00	0.00	0.00
Squirreltail					
	Small	2.14	0.82	0.23	0.03
	Interm	5.26	0.94	2.03	0.22
	Large	0.56	0.95	2.04	0.36
Bluebunch wheatgrass					
	Small	0.90a	0.00	8.11b	0.00 *
	Interm	1.99	0.21	3.34	0.10
	Large	3.98	0.12	3.18	0.00
Cheatgrass					
	Small	0.51	2.15	0.53	2.51
	Interm	3.43	3.52	4.65	0.03
	Large	2.69	0.75	1.23	0.11
Annual grasses					
	Small	0.01	1.48	0.82	0.76
	Interm	6.64	0.16 **	9.76	1.54 **
	Large	0.45a	6.64 **	7.72b	3.32
Perennial forbs					
	Small	7.83	3.08	15.11	3.21 **
	Interm	8.93	3.97	8.22	3.48
	Large	6.13	5.61	11.18	5.31
Annual forbs					
	Small	28.94a	11.78a**	22.97b	4.75b**
	Interm	24.28a	8.52a**	29.94	2.76b**
	Large	23.78	5.87 **	23.74	3.82 **
Sagebrush					
	Small	0.36	0.00a	0.00	13.31b**
	Interm	2.43	3.65	0.97	1.43
	Large	7.74	1.76 *	3.87	3.84
Total					
	Small	59.78	41.90 **	63.30	32.05 **
	Interm	71.39	38.39a**	70.08	15.74b**
	Large	64.83	40.71 **	63.58	27.27 **

[1]Letters denote significant (α =0.05) differences between years within tree sizes and treatments; * denote significant (* =0.05, ** =0.01) differences between tree present and tree removed areas, using Tukey's w-procedure.
[2]Total production does not reflect the sum of individual categories. Miscellaneous species comprise the remainder of total production.

beneath small trees in 1984 and squirreltail production beneath intermediate trees in 1983 were not different. Production of perennial forbs beneath the canopy was greater than interspace production associated with intermediate trees in 1984. Bluebunch wheatgrass production was greater in the interspace than beneath the canopy, regardless of tree size in 1983, and only associated with intermediate trees in 1984. Annual forb production was greater in the interspace associated with most tree sizes - small and large trees in 1983, and large trees in 1984.

Trees Present vs. Trees Removed

Total production was greater with trees removed than with trees present both years, regardless of tree size. Individual species response to tree removal was location and tree size dependent.

First year beneath canopy production with trees removed was greater than production with trees present for cheatgrass, bluebunch wheatgrass, and annual forbs (Table II.1). Production was greater with trees removed than trees present for cheatgrass beneath the canopy of large trees, bluebunch wheatgrass beneath small trees, and annual forbs beneath all tree sizes.

The second year following tree removal, beneath canopy production was greater for cheatgrass for large and intermediate trees; Sandberg bluegrass for small trees; squirreltail for all tree sizes; annual grass for intermediate trees; perennial forbs for intermediate and small trees; and annual forbs for all tree sizes compared to production with trees present.

In 1984 interspace production with trees removed was greater than interspace production with trees present for total production, all tree sizes; Sandberg bluegrass, small and intermediate trees; bluebunch wheatgrass, small trees; and annual forbs, all tree sizes (Table II.2). However, sagebrush production in 1984 was greater with trees present than trees removed only when associated with small trees.

Upper Slope

Trees Present

On the upper slope total production with trees present, based on a 40% to 60% beneath canopy to interspace ratio, was 49.65 g/m^2 (442 lb/A) in 1983 and 42.20 g/m^2 (376 lb/A) in 1984. Unlike total production on the lower slope, there were no differences between years in total understory or total interspace production associated with any tree size class. Individual species showed tree size and location-specific trends in production.

Trees Removed

Total production on the upper slope (moderately deep soils) with trees removed, based on a 40% to 60% beneath canopy to interspace ratio, was 75.01 g/m^2 (668 lb/A) the first year following tree removal and 99.45 g/m^2 (885 lb/A) the second year. Total production beneath the canopy of small and large trees was greater in 1984 than in 1983 (Table II.3). Individual species production varied according to location and tree size. Beneath canopy production was dominated by Idaho fescue, Sandberg bluegrass, squirreltail, cheatgrass, and annual forbs. Sandberg bluegrass and annual forbs dominated interspace production.

Cheatgrass beneath canopy production associated with intermediate and large trees was greater in 1984 than 1983, as was annual forb production beneath large trees. Production of some species decreased the second year after tree removal. Sandberg bluegrass production beneath the canopy of small and intermediate trees was lower in 1984 than in

Table II.3. Mean herbage production on upper slope.

		Beneath Canopy Production in g/m[2]			
Year		1983		1984	
Canopy Status		Removed	Present	Removed	Present
Species	Tree Size				
Sandberg bluegrass					
	Small	18.66a	10.36a**	6.88b	5.05b
	Interm	11.46a	9.37a	6.90b	3.89b
	Large	6.12	4.96	3.72	1.91
Idaho fescue					
	Small	1.89	22.74 **	3.56	15.86 **
	Interm	17.87	8.73 *	15.42	1.68 **
	Large	7.48	8.47	13.72	6.61
Squirreltail					
	Small	10.67	4.41 *	7.36	0.59 **
	Interm	10.32	2.90 **	7.82	1.95 *
	Large	14.77	4.33 **	11.65	5.29 *
Bluebunch wheatgrass					
	Small	5.22	0.89 *	3.76	1.29
	Interm	2.50	1.24	1.16	0.42
	Large	0.94	0.79	0.70	1.21
Cheatgrass					
	Small	1.53	0.38	1.72	0.05
	Interm	7.92a	5.63a	13.11b	7.65 *
	Large	15.92a	7.43a**	24.26b	11.26 **
Annual grasses					
	Small	0.00	0.00	0.02	0.01
	Interm	0.61a	0.05	5.26b	0.20b*
	Large	4.03	1.33	8.26	1.44 **
Perennial forbs					
	Small	1.55	5.07	7.33	3.90
	Interm	16.16	12.81	23.00	16.63
	Large	23.83	22.08	32.41	25.55
Annual forbs					
	Small	13.51a	0.65 *	61.94b	5.17 **
	Interm	32.12	6.07 **	43.05	4.64 **
	Large	18.88a	3.36 **	35.40b	4.85 **
Sagebrush					
	Small	0.28	2.81	0.12	4.15
	Interm	1.28	2.00	1.03	3.57
	Large	0.94	3.20	0.89	3.98
Total					
	Small	59.30a	48.11	92.79b	36.07 **
	Interm	102.65	48.82 **	118.71	40.62 **
	Large	94.75a	56.45 **	135.02b	62.59 **

[1]Letters denote significant (α =0.05) differences between years within tree sizes and treatments; * denote significant (* =0.05, ** =0.01) differences between tree present and tree removed areas, using Tukey's w-procedure.

[2]Total production does not reflect the sum of individual categories. Miscellaneous species comprise the remainder of total production.

1983. The beneath canopy production of annual forbs associated with small trees was also lower in 1984 than 1983.

Total interspace production associated with intermediate and large trees was greater in 1984 than in 1983 (Table II.4). Individual species production was location and tree size dependent. Interspace production of annual grasses associated with large trees was greater in 1984 than 1983. Annual forb interspace production was greater in 1984 than 1983, regardless of tree size. Sandberg bluegrass production in the interspace of all tree sizes was lower in 1984 than 1983.

Total beneath canopy production was greater than total interspace production with trees removed, regardless of tree size, with the exception of total production associated with small trees in 1983. Individual species production showed location and tree size-dependent trends and differences.

Cheatgrass and Idaho fescue production beneath the canopy was greater than interspace production associated with intermediate trees both years, and with large trees in 1984. Idaho fescue production was greater in 1983 only beneath the canopy of intermediate trees. Squirreltail production was

Table II.4. Mean herbage production on upper slope.

Interspace Production in g/m^2					
Year		1983		1984	
Canopy Status		Removed	Present	Removed	Present
Species	Tree Size				
Sandberg bluegrass					
	Small	18.68a	16.35a	9.26b	8.28b
	Interm	17.46a	15.68a	10.33b	7.09b
	Large	15.74a	12.93a	7.36b	5.16b
Idaho fescue					
	Small	3.50	8.86	1.78	3.19
	Interm	2.52	7.29	3.30	4.22
	Large	5.46	8.15	2.71	6.26
Squirreltail					
	Small	4.85	1.09	0.13	0.50
	Interm	1.46	2.40	1.12	0.87
	Large	0.32	2.43	1.93	0.82
Bluebunch wheatgrass					
	Small	0.00	2.07	0.47	1.24
	Interm	0.14	1.39	3.46	1.22
	Large	4.57a	1.39	0.55b	0.63
Cheatgrass					
	Small	0.35	0.03	0.20	0.02
	Interm	0.25	2.28b	0.01	11.65b**
	Large	0.00	3.56	0.01	1.18
Annual grasses					
	Small	0.00	0.02	1.12	0.77
	Interm	0.14a	0.25	5.08b	1.51
	Large	4.57a	1.67a	10.25b	4.78 *
Perennial forbs					
	Small	0.33	1.69	5.92	0.73
	Interm	3.22	5.06	5.88	6.39
	Large	6.02	11.83	7.68	9.88
Annual forbs					
	Small	28.48a	1.73 **	54.15b	8.38 **
	Interm	41.77a	7.05 **	63.17b	12.18 **
	Large	31.02a	6.65 **	64.68b	12.08 **
Sagebrush					
	Small	5.31	4.28	0.01	11.45 **
	Interm	6.50	6.66	2.40	3.04
	Large	2.68	12.73 *	3.16	4.36
Total					
	Small	61.48	36.52 **	73.54	34.54 **
	Interm	75.54a	48.07 **	94.89b	38.16 **
	Large	66.90a	61.44	98.32b	45.44 **

[1]Letters denote significant (α =0.05) differences between years within tree sizes and treatments; * denote significant (* =0.05, ** =0.01) differences between tree present and tree removed areas, using Tukey's w-procedure.

[2]Total production does not reflect the sum of individual categories. Miscellaneous species comprise the remainder of total production.

greater beneath the canopy than in the interspace both years, regardless of tree size. Bluebunch wheatgrass production showed no tree size-related trends and was greater beneath the canopy than in the interspace only when associated with small trees in 1983. Perennial forb production was greater beneath the canopy than in the interspace of intermediate and large trees both years. Production of other species, such as Junegrass (*Koeleria cristata*) and Kentucky bluegrass (*Poa pratensis*) was greater beneath the canopy than in the interspace associated with intermediate trees in 1983, and intermediate and large trees in 1984.

Annual forb and Sandberg bluegrass production tended to be greater in the interspace than beneath the canopy associated with most tree sizes. Annual forb interspace production was greater than beneath canopy production associated with large trees both years, and with intermediate trees in 1984. Sandberg bluegrass interspace production was greater than beneath canopy production only associated with large and intermediate trees.

Trees Present vs. Trees Removed

The difference in production between the trees present and trees removed areas was dramatic on the upper slope. Only small tree beneath canopy and large tree interspace production in 1983 was not greater with trees removed (Tables II.3 and II.4).

The first year after canopy removal, greater total beneath canopy production associated with intermediate and large trees was attributed to cheatgrass, Idaho fescue, squirreltail, and annual forb production (Table II.3). Cheatgrass beneath canopy production was greater with trees removed than with trees present associated with large trees both years, and with intermediate trees in 1984. Idaho fescue production was greater with trees removed than with trees present beneath the canopies of intermediate trees and was lower with trees removed than trees present beneath small trees. Squirreltail and annual forb beneath canopy production was greater with trees removed, regardless of tree size.

Sandberg bluegrass and perennial forb production showed little response following tree removal. Only Sandberg bluegrass production beneath small trees in 1983 was greater with trees removed than trees present. Annual grass beneath canopy production was not different the first year after tree removal, but was greater than production with trees present in 1984 associated with large and intermediate canopies.

Total interspace production was greater with trees removed than with trees present when associated with small and intermediate trees in 1983, and with all tree sizes in 1984 (Table II.4). Cheatgrass interspace production associated with intermediate trees was lower with trees removed compared to production with trees present in 1984. Annual grass production in the interspace of large trees was also greater in 1984 with trees removed compared to trees present.

Greater total interspace production with trees removed was largely due to annual forb production. Annual forb interspace production was greater in the tree removed area, regardless of tree size. Interspace production of sagebrush was lower with trees removed than with trees present associated with large trees in 1983 and small trees in 1984.

DISCUSSION AND CONCLUSIONS

Western juniper canopy removal resulted in an increase in herbage production. Release of understory vegetation from competition with western juniper appeared to compensate for differences in growing season precipitation, since precipitation patterns appeared to have less effect on production in the tree removed areas than in areas with trees present. The release from competition for moisture (Jeppeson 1978) and nutrients (Evans and Young 1985) may have caused the greater total understory production. Some species appeared not to be affected by tree removal. Production of Sandberg bluegrass seemed more closely tied to growing season precipitation than any tree-induced effects.

The type and magnitude of biomass production response to tree removal, as seen from the results of this study, were closely tied to location and tree canopy size. With harvest of large trees, response of vegetation occurred primarily beneath the canopy and resulted in an increase in cheatgrass, perennial forb, and annual forb production. The proportion of annual forbs increased as the size of the tree removed decreased.

Other studies in pinyon-juniper woodlands have shown increases in understory production following tree removal (Kruse et al. 1979, Clary and Jameson 1981). In this study, total production increased 33% from 1983 to 1984, with the greatest increase occurring in production of annual forbs. Perennial grasses such as squirreltail showed some increase in production with tree removal, while others, such as Idaho fescue were either unaffected or even diminished. A peak in weedy annual production following tree removal was observed by Barney and Frischknecht (1974) in singleleaf pinyon- Utah juniper woodlands. In that study perennial species dominated the site by the fifth or sixth year following tree removal. Everett and Ward (1984) suggested succession after tree removal followed several pathways and early plant community development was a product of the type of disturbance, species pool, and timing of disturbance. The production of annuals may have been influenced by the above-average precipitation the two years of this study and perennial species may eventually again dominate the study sites.

Based on 2 years of data, western juniper tree removal as a method to increase forage production may not be economically feasible or achieve desired results over a short time period. However, the positive response of some desireable species suggests the area may someday support a richer flora.

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SUMMARY

The encroachment of grasslands by woody species has greatly affected the nature of many western rangelands. Woody species in the Intermountain West and Great Basin, such as pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.) have been shown to negatively affect production and change the composition of associated vegetation. Tree removal has resulted in greater production on these sites. Plant communities dominated by western juniper (*Juniperus occidentalis*) also show these types of impacts on associated vegetation and similar management practices have been applied. Recent evidence, however, suggests western juniper communities may not respond to management in the same manner as pinyon-juniper communities. This study examined the effect of tree size on understory vegetation and the response of understory vegetation to western juniper removal.

Some individual species showed year-to-year differences and production dependent upon location and

tree size. Growing season precipitation patterns during the study, in combination with tree size effects may partially account for observed variation in the production. The difference in growing season precipitation probably had the greatest impact on vegetation associated with small trees. May precipitation in 1983 was approximately 6 times greater than May precipitation in 1984. Sandberg bluegrass and, possibly, Idaho fescue production may be sensitive to late spring precipitation. Production of both these species was greater in 1983 than in 1984.

Differences in species composition between the two sites are likely due to soil depth and its effect on soil moisture. Total production tended to be greater on the upper slope than on the lower slope. The shallow soils on the lower slope supported more squirreltail and cheatgrass than the upper slope. The moderately deep soils of the upper slope supported greater quantities of Idaho fescue and perennial forbs. Annual forb production was similar on the two areas and may not be influenced by soil depth.

The effect of western juniper trees on understory vegetation was also tree size related. Cheatgrass and perennial forb production beneath the canopy was greater with increase in tree size. The production of other species, such as Sandberg bluegrass, was not affected by tree size.

Species-specific patterns developed beneath the canopy and in the interspace. The cooler and more moist conditions, along with, probably, greater nutrient concentrations beneath the canopy favored the production of Idaho fescue, squirreltail, cheatgrass, and perennial forbs. Sandberg bluegrass, annual forb, and sagebrush production was greater in the warmer and drier interspaces. These production patterns were most clearly developed around large trees.

Western juniper canopy removal resulted in increased herbage production of most species. Production of Sandberg bluegrass, however, seemed more closely tied to growing season precipitation than any tree-induced effects. The response was closely tied to location and tree canopy size. Response to the harvest of large trees occurred primarily beneath the canopy. Cheatgrass, perennial forb, and annual forb production increased. Annual forbs, especially fireweed (Epilobium paniculatum), increased greatly and the proportion of annual forbs relative to other species increased as tree size decreased. Perennial grasses such as squirreltail showed some increase in production with tree removal, while others, such as Idaho fescue, were either unaffected or even diminished.

The future production and composition of these sites is difficult to predict on the basis of a two year study. These results show that tree removal does not necessarily result in a greater production of desirable species over a short time period. Most of the increase in production observed was from annual forbs. Above average precipitation the two years of the study, however, may account for the flush of annual production following tree removal. The positive response of some of the perennial species suggests the area may, in the future, support a richer flora.

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APPENDICES

Appendix 1. Scientific name and common name of plant species occurring on the study area.

Scientific Name	Common Name
Grasses	
Agropyron spicatum	bearded bluebunch wheatgrass
Bromus brizaeformis	rattle brome
Bromus carinatus	mountain brome
Bromus japonicus	Japanese brome
Bromus mollis	soft brome
Bromus tectorum	cheatgrass brome
Festuca idahoensis	Idaho fescue
Festuca octoflora	sixweeks fescue
Koeleria cristata	prairie junegrass
Poa ampla	big bluegrass
Poa compressa	Canada bluegrass
Poa pratensis	Kentucky bluegrass
Poa sandbergii	Sandberg bluegrass
Sitanion hystrix	bottlebrush squirreltail
Stipa thurberiana	Thurber needlegrass
Forbs	
Achillea millefolium	common yarrow
Agoseris glauca	pale agoseris
Allium lemmonii	Lemon's onion
Antennaria dimorpha	low pussytoes
Aster campestris	western meadow aster
Astragalus curvicarpus	curvepod loco
Astragalus filipes	basalt milkvetch
Astragalus purshii	Pursh's milkvetch
Astragalus reventus	longleaf milkvetch
Blepharipappus scaber	blepharipappus
Calochortus macrocarpus	sagebrush mariposa
Castilleja spp.	desert paintbrush
Chaenactis douglasii	Douglas chaenactis
Cirsium spp.	thistle
Clarkia pulchella	rose clarkia
Collinsia parviflora	littleflower collinsia
Collomia grandiflora	bigflower gilia
Cordylanthus ramosus	bushy birdbeak
Crepis acuminata	tapertip hawksbeard
Cryptantha ambigua	obscure cryptantha

Appendix 1. (Continued)

Scientific Name	Common Name
Forbs (continued)	
Descurania pinnata	pinnate tanseymustard
Descurania richardsonii	Richardson tanseymustard
Epilobium paniculatum	autumn willowweed
Erigeron linearis	lineleaf fleabane
Erigeron poliospermus	cushion fleabane
Eriogonum heracleoides	Wyeth eriogonum
Eriogonum niveum	snow eriogonum
Eriogonum ovalifolium	cushion eriogonum
Eriogonum sphaeracephalum	rock eriogonum
Eriogonum stricta	strict buckwheat
Eriophyllum lanatum	woolly eriophyllum
Erodium cicutarium	filaree
Fritillaria pudica	yellow fritillary
Hydrophyllum spp.	waterleaf
Kobresia simpliciuscula	simple kobresia
Lepidium perfoliatum	clasping pepperweed
Leptodactylon pungens	granite gilia
Lithophragma spp.	woodlandstar
Lomatium cous	cous bisquitroot
Lupinus caudatus	tailcup lupine
Lupinus lepidus	Pacific lupine
Lupinus macrocarpus	chick lupine
Madia sativa	Chilean tarweed
Mimulus breweri	crimson monkeyflower
Montia perfoliata	miner's lettuce
Penstemon laetus	gay penstemon
Phacelia linearis	thread phacelia
Phlox hoodii	Hood's phlox
Ranunculus occidentalis	western buttercup
Sanguisorba minor	small burnet
Senecio canus	woolly groundsel
Sisymbrium altissimum	tumblemustard
Sisyrinchium douglasi	Douglas blue-eyed grass
Tetradymia glabrata	littleleaf horsebrush

Appendix 1. (Continued)

Scientific Name	Common Name
Forbs (continued)	
Tragopogon dubius	yellow salsify
Trifolium macrocephalum	bighead clover
Trifolium microcephalum	woolly clover
Verbascum thapsus	flannel mullein
Zigadenus paniculatus	foothill death camas
Shrubs and Trees	
Artemisia arbuscula	low sagebrush
Artemisia tridentata ssp. *tridentata*	basin big sagebrush
Artemisia tridentata ssp. *wyomingensis*	Wyoming big sagebrush
Artemisia tridentata ssp. *vaseyana*	mountain big sagebrush
Chrysothamnus nauseousus	gray rabbitbrush
Chrysothamnus viscidiflorus	green rabbitbrush
Ribes cereum	wax currant
Artemisia rigida	stiff sagebrush
Juniperus occidentalis	western juniper

Appendix 2. Herbage production along transect directions - lower slope (g/m2).

Tree Size / Transect Direction / Species	Zone / Year	Northeast	Northwest	Southwest	Southeast
Small	Beneath Canopy				
Sandberg bluegrass					
	1983	7.79	10.67	13.33	12.77 1
	1984	6.44	3.68	6.63	3.45 2
Idaho fescue					
	1983	0.00	0.00	0.00	0.00
	1984	0.00	0.00	0.00	0.00
Squirreltail					
	1983	10.51ab	9.16ab	4.19a	21.77b1
	1984	1.12	1.83	1.12	2.50 2
Bluebunch wheatgrass					
	1983	0.00	0.00	0.35	0.00
	1984	0.00	0.00	0.00	0.00
Cheatgrass					
	1983	14.53	8.73	9.54	15.01
	1984	1.61	1.25	2.10	2.06
Annual grasses					
	1983	2.72	0.02	0.04	0.02
	1984	0.34	0.03	0.03	0.05
Perennial forbs					
	1983	3.48	0.23	0.00	0.00
	1984	0.34	0.94	3.57	1.69
Annual forbs					
	1983	9.54	4.72	10.23	12.98
	1984	5.19	2.34	4.67	3.67
Sagebrush					
	1983	0.00	0.00	0.00	0.00
	1984	0.00	0.07	0.00	0.00
Miscellaneous					
	1983	0.00	0.00	0.00	0.00
	1984	0.00	0.00	0.00	0.00
Total					
	1983	48.57 1	33.52	37.67	62.48 1
	1984	15.03 2	10.14	18.11	13.42 2

[1] Letters denote significant (α=0.05) differences between beneath transect directions within species and within years, using Tukey's w-procedure; numbers denote significant (α=.05) differences between years within species.

Appendix 2. (Continued)

Tree Size / Transect Direction / Species	Year	Zone: Northeast	Northwest	Southwest	Southeast
Small		Interspace			
Sandberg bluegrass					
	1983	27.14a1	14.22b1	21.20ab1	17.84ab
	1984	9.46 2	2.93 2	8.28 2	10.70
Idaho fescue					
	1983	0.00	0.00	0.00	0.00
	1984	0.00	0.00	0.00	0.00
Squirreltail					
	1983	2.96	0.00	0.30	0.00
	1984	0.00	0.12	0.00	0.00
Bluebunch wheatgrass					
	1983	0.00	0.00	0.00	0.00
	1984	0.00	0.00	0.00	0.00
Cheatgrass					
	1983	2.26	1.26	1.80	3.26
	1984	0.91	0.08	1.02	6.60
Annual grasses					
	1983	3.66	0.04	0.00	2.22
	1984	0.31	0.05	0.04	2.64
Perennial forbs					
	1983	5.18	0.00	0.86	6.26
	1984	1.15	5.84	3.10	2.76
Annual forbs					
	1983	11.82	9.78	12.34	13.18
	1984	2.49	3.65	4.70	8.18
Sagebrush					
	1983	0.00	0.00 1	0.00	0.00 1
	1984	1.16a	25.58b2	0.00a	26.48b2
Miscellaneous					
	1983	0.00	0.00	0.00	0.00
	1984	0.00	0.00	0.00	0.00
Total					
	1983	53.02 1	35.30	36.50	42.76
	1984	15.47a2	38.25ab	17.14a	57.36b

Appendix 2. (Continued)

Tree Size / Transect Direction / Species	Zone / Year	Northeast	Northwest	Southwest	Southeast
Intermediate	Beneath Canopy				
Sandberg bluegrass					
	1983	8.65	10.60	12.08	9.65
	1984	4.25	4.85	4.22	3.14
Idaho fescue					
	1983	0.00	0.00	0.00	0.00
	1984	0.00	0.00	0.00	0.00
Squirreltail					
	1983	3.54	1.11	2.62	6.06
	1984	1.42	0.88	0.64	1.19
Bluebunch wheatgrass					
	1983	9.73	0.92	1.92	0.94
	1984	0.00	0.00	1.26	2.68
Cheatgrass					
	1983	6.47	6.97	5.29	18.88
	1984	4.21	2.96	3.74	8.19
Annual grasses					
	1983	1.86	0.01	0.00	0.01
	1984	1.07	0.08	0.01	2.43
Perennial forbs					
	1983	4.52	2.80	5.85	4.94
	1984	3.60	1.12	2.30	2.14
Annual forbs					
	1983	6.54	5.09	4.92	7.27
	1984	6.49	3.19	3.18	4.06
Sagebrush					
	1983	0.27	0.61	0.05	5.98
	1984	0.00	0.00	0.00	4.10
Miscellaneous					
	1983	0.01	0.00	0.00	0.00
	1984	0.00	0.00	0.00	0.00
Total					
	1983	41.59	28.11	32.73	53.73
	1984	21.04	13.08	15.25	27.93

Appendix 2. (Continued)

Tree Size / Zone / Transect Direction / Species Year	Northeast	Northwest	Southwest	Southeast
Intermediate Interspace				
Sandberg bluegrass				
1983	17.77 1	13.91	22.68 1	15.21 1
1984	7.13 2	5.41	7.11 2	5.28 2
Idaho fescue				
1983	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00
Squirreltail				
1983	1.14	0.77	0.85	1.00
1984	0.00	0.47	0.22	0.19
Bluebunch wheatgrass				
1983	0.26	0.00	0.38	0.21
1984	0.17	0.00	0.00	0.22
Cheatgrass				
1983	1.37	0.02	1.59	11.08
1984	0.03	0.03	0.03	0.03
Annual grasses				
1983	0.13	0.50	0.01	0.00
1984	0.50	0.02	1.41	4.25
Perennial forbs				
1983	5.55	5.81	2.89	1.64
1984	2.97	4.05	4.36	2.53
Annual forbs				
1983	10.66	3.63	4.42	15.37
1984	3.40	1.27	1.45	4.94
Sagebrush				
1983	2.37	0.85	4.32	7.05
1984	1.08	0.00	0.00	4.64
Miscellaneous				
1983	0.00	0.02	0.00	0.00
1984	0.00	0.00	0.00	0.00
Total				
1983	39.25	25.52	37.14	51.66
1984	15.28	11.25	14.58	22.07

Appendix 2. (Continued)

Tree Size / Transect Direction / Species	Year	Zone: Northeast	Northwest	Southwest	Southeast
Large		Beneath Canopy			
Sandberg bluegrass					
	1983	8.41	13.33	10.55	6.65
	1984	6.36	11.49	7.40	4.64
Idaho fescue					
	1983	0.00	0.00	0.00	0.00
	1984	0.00	0.00	0.00	0.00
Squirreltail					
	1983	6.98a	3.45a	4.29a	21.19b1
	1984	2.43	1.42	2.05	6.97 2
Bluebunch wheatgrass					
	1983	2.12	1.07	0.57	0.00
	1984	0.19	0.20	0.38	0.00
Cheatgrass					
	1983	31.49a	12.56ab	8.30b	17.65ab
	1984	14.78	8.48	11.16	16.59
Annual grasses					
	1983	2.89	1.13	0.01	0.63
	1984	2.32	1.29	1.26	1.14
Perennial forbs					
	1983	4.30	4.47	5.13	5.30
	1984	7.97	2.32	4.95	5.79
Annual forbs					
	1983	5.98	5.20	6.29	7.43
	1984	6.70	5.56	5.27	9.81
Sagebrush					
	1983	0.17	0.16	7.72	6.03
	1984	0.17	0.00	3.09	1.26
Miscellaneous					
	1983	0.00	0.00	0.00	0.01
	1984	0.00	0.00	0.00	0.01
Total					
	1983	62.34	41.37	42.86	64.89
	1984	40.92	30.76	35.56	46.21

Appendix 2. (Continued)

Tree Size / Transect Direction / Species	Year	Northeast	Northwest	Southwest	Southeast
Large	**Interspace**				
Sandberg bluegrass					
	1983	23.65 1	17.02	21.08 1	14.34
	1984	10.58 2	15.41	9.07 2	5.96
Idaho fescue					
	1983	0.00	0.00	0.00	0.00
	1984	0.00	0.00	0.00	0.00
Squirreltail					
	1983	1.04	1.05	1.37	0.35
	1984	0.80	0.01	0.39	0.26
Bluebunch wheatgrass					
	1983	0.00	0.31	0.18	0.00
	1984	0.00	0.00	0.00	0.00
Cheatgrass					
	1983	0.03	0.23	0.02	2.67
	1984	0.03	0.46	0.03	0.94
Annual grasses					
	1983	5.31a	18.24b1	0.66a	2.37a
	1984	2.72	4.00 2	1.33	5.22
Perennial forbs					
	1983	6.59	7.20	5.59	3.04
	1984	2.86	10.10	3.43	4.86
Annual forbs					
	1983	6.64	4.28	3.09	9.47
	1984	4.77	3.35	1.75	5.43
Sagebrush					
	1983	0.56	2.15	2.88	1.43
	1984	3.07	1.02	4.67	6.58
Miscellaneous					
	1983	0.00	0.00	0.01	0.00
	1984	0.00	0.00	0.00	0.00
Total					
	1983	43.82	50.48	34.88	33.67
	1984	24.83	34.35	20.67	29.24

Appendix 3. Herbage production along transect directions - upper slope.

Tree Size / Transect Direction / Species / Year		Northeast	Northwest	Southwest	Southeast
Small		Beneath Canopy			
Sandberg bluegrass					
	1983	11.27ab	1.37a	11.97b1	16.81b1
	1984	7.31	1.87	2.96 2	8.08 2
Idaho fescue					
	1983	15.75ab	34.17a	31.86a	9.16b
	1984	6.24a	26.97b	13.29ab	16.95ab
Squirreltail					
	1983	7.80	4.15	5.47	0.23
	1984	0.02	0.17	2.18	0.00
Bluebunch wheatgrass					
	1983	0.00	2.06	0.00	1.51
	1984	4.30	0.00	0.00	0.84
Cheatgrass					
	1983	0.03	0.05	1.37	0.06
	1984	0.02	0.04	0.09	0.04
Annual grasses					
	1983	0.00	0.00	0.00	0.00
	1984	0.00	0.00	0.02	0.02
Perennial forbs					
	1983	4.75	14.48	0.98	0.06
	1984	0.74	2.22	8.28	4.37
Annual forbs					
	1983	1.04	0.07	0.28	1.20
	1984	9.16	3.56	5.44	2.51
Sagebrush					
	1983	1.12	0.00	7.93	2.18
	1984	0.00	6.14	10.47	0.00
Miscellaneous					
	1983	0.00	0.00	3.26	0.00
	1984	0.00	0.00	0.00	0.00
Total					
	1983	41.76	56.35	63.12	31.21
	1984	27.79	40.97	42.72	32.80

[1]Letters denote significant (α=0.05) differences between beneath transect directions within species and within years, using Tukey's w-procedure; numbers denote significant (α=.05) differences between years within species.

Appendix 3. (Continued)

Tree Size / Transect Direction / Species Year	Zone			
	Northeast	Northwest	Southwest	Southeast
Small	Interspace			
Sandberg bluegrass				
1983	7.51a	19.66b1	21.12b1	17.12ab
1984	9.00	6.04 2	5.92 2	12.16
Idaho fescue				
1983	8.54	6.66	6.20	14.02
1984	4.98	2.74	4.28	0.76
Squirreltail				
1983	0.68	0.02	0.00	3.64
1984	0.62	0.92	0.02	0.44
Bluebunch wheatgrass				
1983	0.00	1.46	0.00	6.82
1984	0.02	0.00	0.82	4.10
Cheatgrass				
1983	0.04	0.00	0.02	0.04
1984	0.00	0.02	0.02	0.02
Annual grasses				
1983	0.02	6.66	0.02	0.00
1984	0.02	1.82	1.04	0.02
Perennial forbs				
1983	0.07	3.36	2.34	0.02
1984	0.02	7.52	3.52	8.79
Annual forbs				
1983	1.18	0.00	16.80	0.00
1984	13.70	7.52	3.52	8.79
Sagebrush				
1983	0.00	0.00	16.80	0.00
1984	0.00a	12.36ab	23.20b	10.22ab
Miscellaneous				
1983	0.00	0.86	1.14	0.00
1984	0.00	0.00	0.00	0.00
Total				
1983	18.04	38.70	47.66	41.68
1984	28.36	33.84	39.42	36.53

Appendix 3. (Continued)

Tree Size / Zone Transect Direction Species Year		Northeast	Northwest	Southwest	Southeast
Intermediate Beneath Canopy					
Sandberg bluegrass					
	1983	7.39ab	3.18a	11.17ab	15.74b1
	1984	1.51	5.48	4.12	4.45 2
Idaho fescue					
	1983	15.73	10.71	3.02	5.45
	1984	2.51	3.09	0.74	0.38
Squirreltail					
	1983	2.32	3.41	2.47	3.39
	1984	2.21	1.03	2.55	2.02
Bluebunch wheatgrass					
	1983	1.81	0.46	2.03	0.64
	1984	0.00	0.20	1.47	0.01
Cheatgrass					
	1983	7.42	4.61	4.23	6.26
	1984	7.27	6.53	8.09	8.72
Annual grasses					
	1983	0.20	0.00	0.00	0.00
	1984	0.59	0.01	0.17	0.01
Perennial forbs					
	1983	19.42	19.87	9.85	2.11
	1984	21.64	6.57	23.211	15.09
Annual forbs					
	1983	14.60	5.97	1.40	2.42
	1984	4.21	6.33	4.90	3.12
Sagebrush					
	1983	0.01	0.01	4.14	3.85
	1984	2.47	1.09	6.99	3.72
Miscellaneous					
	1983	0.00	0.00	0.00	0.00
	1984	0.01	0.00	0.00	0.00
Total					
	1983	68.90	48.22	38.31	39.86
	1984	42.41	30.32	52.25	37.52

Appendix 3. (Continued)

Tree Size / Transect Direction / Species Year	Zone					
	Northeast	Northwest	Southwest		Southeast	
Intermediate	**Interspace**					
Sandberg bluegrass						
1983	14.94	11.46a	19.86	1	16.44	1
1984	7.18	8.20	7.34	2	5.64	2
Idaho fescue						
1983	12.93	4.81	4.98		6.45	
1984	3.25	6.82	1.89		4.90	
Squirreltail						
1983	0.14	2.30	5.14		2.00	
1984	0.31	1.47	0.01		1.68	
Bluebunch wheatgrass						
1983	2.54	1.22	0.44		1.35	
1984	1.28	1.79	1.82		0.00	
Cheatgrass						
1983	2.11	1.02	0.92		5.06	
1984	0.95	0.59	0.02		5.06	
Annual grasses						
1983	1.01	0.00	0.00		0.00	
1984	0.03	0.02	5.96		0.02	
Perennial forbs						
1983	5.33	4.00	9.32		1.61	
1984	3.70	5.40	5.60		10.84	
Annual forbs						
1983	4.35	4.33	3.97		15.57	
1984	10.52	11.23	11.41		15.57	
Sagebrush						
1983	4.54	9.57	6.27		6.27	
1984	0.00	1.16	4.63		6.34	
Miscellaneous						
1983	0.00	0.00	0.00		0.00	
1984	0.00	0.00	0.00		0.00	
Total						
1983	47.88	38.70	50.92		54.76	
1984	27.22	36.68	38.69		50.04	

Appendix 3. (Continued)

Tree Size / Zone / Transect Direction / Species	Year	Northeast	Northwest	Southwest	Southeast
Large		Beneath Canopy			
Sandberg bluegrass					
	1983	2.55	2.86	9.40	5.02
	1984	0.86	1.88	2.30	2.58
Idaho fescue					
	1983	17.84	12.33	1.20	2.52
	1984	8.74	5.94	2.66	9.08
Squirreltail					
	1983	5.03	1.89	5.30	5.09
	1984	5.20	3.03	5.22	7.69
Bluebunch wheatgrass					
	1983	0.24	2.02	0.20	0.70
	1984	0.64	2.01	1.25	0.92
Cheatgrass					
	1983	9.49	7.77	5.76 1	6.74
	1984	12.72	9.62	16.54 2	6.16
Annual grasses					
	1983	0.01	5.11	0.00	0.19
	1984	0.01	3.16	0.20	2.39
Perennial forbs					
	1983	19.62	26.33	21.14	21.24
	1984	20.34	30.06	24.21	27.57
Annual forbs					
	1983	1.86	2.27	7.59	1.74
	1984	6.93	3.05	4.70	4.71
Sagebrush					
	1983	2.12	2.94	6.11	1.64
	1984	5.61	1.32	7.09	1.87
Miscellaneous					
	1983	0.00	0.41	0.00	1.56
	1984	0.10	0.00	0.00	1.98
Total					
	1983	58.71	63.93	56.71	46.45
	1984	61.15	60.08	64.18	64.96

Appendix 3. (Continued)

Tree Size / Transect Direction / Species Year	Zone Northeast	Northwest	Southwest	Southeast
Large	**Interspace**			
Sandberg bluegrass				
1983	12.60 1	13.30	14.20	11.62
1984	4.08 2	5.47	5.91	5.53
Idaho fescue				
1983	11.07	14.34	4.59	2.59
1984	9.57	5.45	2.71	7.28
Squirreltail				
1983	6.69	0.31	0.60	2.11
1984	0.48	1.13	0.20	1.48
Bluebunch wheatgrass				
1983	1.59	0.74	2.98	0.25
1984	0.52	0.65	1.05	0.30
Cheatgrass				
1983	1.85	0.28	3.70	8.42
1984	0.02	0.02	4.43	0.23
Annual grasses				
1983	0.47	6.19	0.00	0.00
1984	6.18	9.65	0.51	2.79
Perennial forbs				
1983	37.68a	2.47b	2.70b	4.48b
1984	22.18	8.73	5.66	2.95
Annual forbs				
1983	10.91	8.32	4.68	2.69
1984	13.83	8.65	12.86	12.99
Sagebrush				
1983	5.73a	0.79a	10.95a	33.45b1
1984	1.45	2.30	6.16	7.52 2
Miscellaneous				
1983	0.00	0.00	0.00	0.44
1984	0.00	0.00	0.00	0.83
Total				
1983	88.58a	46.74ab	44.40b	66.05ab
1984	58.31	42.06	39.49	41.92