AN ABSTRACT OF THE THESIS OF

Wendy Sims Waichler for the degree of Master of Science in Rangeland Resources presented on September 25, 1998. Title: Community Structure of Old-Growth *Juniperus occidentalis* Woodlands.

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Knowledge of old-growth *Juniperus occidentalis* woodlands, which occur in central and eastern Oregon, is limited. Wise management of these woodlands necessitates a better understanding of the community ecology. The community structure of woodlands at seven sites in three areas of central Oregon was studied. Measurements taken at nine plots per site included tree density, canopy cover, heights, diameters, and canopy areas; cover of each understory species and other ground covers; density of shrubs by species and condition; density of woody debris as downed pieces and standing dead trees; and topographic and soil parameters. Tree cores were taken for aging, although heartwood rot is pervasive in older trees. Factors of interest included cover and richness in all vegetative layers, variability within and between sites, and comparison of *J. occidentalis* woodlands to other old-growth communities. *J. occidentalis* woodlands were found to have a minimum of 80 trees over 200 years old per hectare, canopy cover of 10-35%, and understory cover of less than 20%. Woody detritus was primarily retained aloft and decomposed by weathering. Tree morphology was highly variable, but decadence was common. Outward physical attributes did not appear to be reliable predictors of tree age. Shrub cover was strongly correlated ($r^2 = 0.66$) with the combination of elevation, ground cover by rock, and clay content of the soil. Perennial grass cover increased with elevation and the sand-sized soil fraction ($r^2 = 0.46$). Understory cover, dominated by perennial grass, showed a weaker correlation with the same parameters ($r^2 = 0.20$). Other significant findings included correlation of juniper

cover with elevation, sand, and heat load ($r^2 = 0.38$). Tree cover was found to increase by almost 1% for each 1% increase in sand content of the soil and by almost 8% for each 100m increase in elevation, while heat load, based on aspect, had a smaller effect. Plots grouped strongly by area, suggesting that there is a stronger influence of area than site on community composition for most of the sites and that differences between areas overwhelm the differences within areas.

Community Structure of Old-Growth *Juniperus occidentalis* Woodlands

by

Wendy Sims Waichler

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Wendy Sims Waichler, Author

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DEDICATION

I dedicate this work to my baby daughter, Claire Elana. May she find joy in the natural world and enjoy a lifetime of wonder and learning.

Community Structure of Old-Growth *Juniperus occidentalis* Woodlands

INTRODUCTION

Western juniper, *Juniperus occidentalis* Hook var. *occidentalis* Vasek, is the only tree species found in much of the portion of Oregon that lies in the northwestern Great Basin. Its rapid expansion beyond its historic range and density in eastern Oregon has caused significant concern about the future health and productivity of the areas it occupies. Numerous authors have described detrimental changes that take place during the transition from a sagebrush-steppe community to a fully developed *J. occidentalis* woodland (Adams 1975, Bates 1996, Bedell and Bunch, 1978, West, Rea, and Tausch 1975). Changes frequently cited include declines in cover, species richness, shrubs, and soil depths, with resultant impacts on animal habitat, and the flow of water, nutrients, and energy (Eddleman et al. 1994).

Despite this concern, little is known about the latter stages of community development in stands of this species. Reports in the literature on *J. occidentalis* stands are believed to be on transitional woodlands, with site characterization generally insufficient to determine community development status (see Eddleman et al. 1994). The limited work done on individual old-growth *J. occidentalis* trees does not provide community level understanding. Since neither fully developed nor old-growth *J. occidentalis* woodlands have been studied, the community characteristics that can be expected as transitional stands become fully developed remain uncertain. Steady-state conditions can be expected once a community has reached this stage.

Understanding the site potential and characterization for different site types that support *J. occidentalis* is critical to making appropriate management decisions. In transitional areas, it is important that the influence of site potential on eventual stand structure be understood. Aspect, slope, and soils, particularly soil texture and depth, strongly affect site characteristics. For example, on deep loamy soils (e.g. Pachic Haploxerolls), a high level of herbaceous understory cover is able to persist under juniper dominance (Miller et al.1995). A functional definition of old-growth *J. occidentalis* is further necessitated in response to old-growth preservation efforts that have begun in some areas.

The purpose of the current study is to characterize old-growth *J. occidentalis* communities in an area of central Oregon. Attributes of interest include cover and richness in all vegetative layers, variability within and between sites, and comparison of *J. occidentalis* woodlands to other old-growth communities, as well as a description of old-growth community characteristics and an analysis of the effect of topographic variation. It is hoped that the information collected will be useful to land managers for managing existing old-growth woodlands and for predicting steady-state conditions for similar sites on which juniper has been increasing in this century. While potentially significant, it is beyond the scope of this study to take into account any differences between current climatic conditions and conditions that existed when the old-growth communities established.

LITERATURE REVIEW

General description of Juniperus occidentalis var. occidentalis

J. occidentalis has been shown to be a long-lived, primarily single-stemmed tree species reaching fifteen meters in height with bark that is cinnamon-brown, furrowed, and stringy (Vasek 1966, Hitchcock et al. 1969). Burkhardt and Tisdale (1969) described two growth forms: the old, or presettlement, tree form being large and heavily-limbed from near the base, with round-topped crowns lacking strong terminal leaders, and the younger, or postsettlement, trees in invading stands having conical-shaped crowns and prominent terminal leaders.

Mature trees have 3 mm long scale-like leaves which occur in twos or, most often, threes. Vasek (1966) found prominent glands on the dorsal surface that exude resin which dries to a white color in the fall. Structural adaptations which increase drought avoidance included low leaf area, low surface-to-volume ratios, thick cuticle layers, and protected stomates. Under electron microscopes, stomates were found on the underside of the leaf and on the portion of the upper surface covered by the overlapping neighboring leaf (Miller and Shultz 1987). The leaves of juvenile plants differ, being awl-like and 5-7 mm long (Hitchcock et al.1969).

The male cones were shown to initiate growth in the summer, then mature to three to five millimeters long and shed pollen the following spring. Female cones resembled and are commonly referred to as berries(Vasek 1966). They were small (7-8 mm), sub-globose, and glaucous-blue, with 1-3 seeds (Hitchcock et al. 1969). The berries appeared mostly on the outside of the canopy (Lederer 1977) beginning as early as January or February, reached essentially full size in the first summer, matured during the second summer, and fell off during the following autumn and winter (Vasek 1966).

Sex expression change occurs in the *Juniperus* genus, but has not been sufficiently reported on for *J. occidentalis*. Vasek described the species as submonoecious. On Steens Mountain Oregon, *J. occidentalis* approached full reproductive potential near 50 years of age (Miller and Rose 1995). Eddleman reports finding fruit on trees as young as 25 years old, with significant production beginning at 50-70 years of age (Eddleman 1984).

Principal seed dispersal mechanisms appear to have been wildlife and downslope transport, although research in this area is scarce. In a wintertime study in the northern Sierras, Lederer (1977) found *J. occidentalis* berries to be the sole food for Townsend's solitaires. Analyses of both solitaire and American robin digestive tracts found only *J. occidentalis* berries and remnants. *Juniperus* berries have also been reported in the diets of Stellars Jays, scrub jays, coyotes, and rabbits (Gabrielson and Jewett 1970, Johnsen 1962). Winter use by mountain bluebirds has been observed (R.F. Miller, personal observation). After ingestion, the seeds were disseminated, as they are not digested (Hitchcock et al. 1969). Eddleman (1984) observed seed dispersal by water flowing over frozen ground.

Establishment and growth

J. occidentalis development is difficult to generalize, due to its ability to grow in a wide range of conditions, including variations in soils, climate, and competition. Young et al. (1988) found that seeds are highly dormant at maturation, that emergence from seeds from a single year likely occurs over a period of several years, and that potential germination is high under appropriate conditions, which include prolonged cool-moist stratification.

J. occidentalis appears to establish most successfully in the modified microclimate of a woody nurse plant. Common nurse plants are reported to be *Artemisia* species and, in established stands, *J. occidentalis* (Burkhardt and Tisdale 1976, Eddleman 1987, Miller and Rose 1995). Reported growth rates of young trees ranged from 1.4-3.4 cm/year (Burkhardt and Tisdale 1976) and from 2.4 cm/year in interspaces to 3.4 cm/year under *Artemisia* species (Miller and Rose 1995).

Structure has varied considerably between woodlands. Postsettlement woodlands have tended to be relatively even-aged. In closed stands in *Artemisia tridentata* ssp.

vaseyana Nutt. sites on Steens Mountain, Miller and Rose (1995) found densities as high as 876 trees/hectare, of which 580 were juveniles under 0.5 meters tall. *Artemisia arbuscula* Nutt. sites had 257 trees/hectare, with 99 juveniles/hectare. Mean canopy cover in the *A. tridentata* ssp. *vaseyana* sites was 22%. In stands dominated by mature trees, densities of 138-425 trees per hectare and canopy cover averaging 47% and reaching 86% in aspen stands were found. Both standing dead trees and down wood were rare in younger woodlands but numerous in the mature stands (Burkhardt and Tisdale 1969).

Once established, *J. occidentalis* mortality rates appear to be low. Insects and disease appear to cause little mortality. Fire will cause mortality of younger trees. Trees under 2 meters (Martin 1978) or less than forty to fifty years of age (Burkhardt and Tisdale 1976) were killed easily by fire, but greater fire intensities were needed to cause mortality in taller trees.

Species richness has been reported to be lower in old woodlands than in young woodlands. Burkhardt and Tisdale (1969) compared stands of young trees (33-88 years) to older stands. The latter sites were interpreted as having climax vegetation, with older trees (185-365 years), numerous large dead junipers, and rotted stumps. Fewer shrubs, perennial grasses, and perennial forbs were found in the old woodlands. Only two shrubs, five perennial and one annual grass, seven perennial and four annual forbs, and one moss were measured in summer in the old woodlands. The lichen, *Letharia* sp., was found only in the old woodlands. Its bright yellow color made it a conspicuous marker for dead or dying branches, where it grew on the bare wood.

Distribution

The species *Juniperus occidentalis* has been separated into two subspecies (Vasek 1966). *J. occidentalis* Hook. ssp. *australis* occurs to the south of the *J. occidentalis* ssp. *occidentalis* range. The subspecies of interest here, *J. occidentalis* ssp. *occidentalis*, occurs in a wide variety of vegetation types, soils, elevations, and moisture regimes. Its range is primarily north of the polar front gradient which runs parallel to the Oregon/Nevada border at latitude 42° (Neilson 1987) where the climate is cooler, with less summer precipitation and more winter precipitation (Mitchell 1976). The range has been shown to extend from Lassen County, California north through Oregon and from southwestern Idaho west to the Cascade Mountains. West of the Cascades, it also extended from Trinity County California to southern Jackson County Oregon. Scattered stands occurred in southern Washington and in northwestern Nevada. It was sparse in northeastern Oregon and widely distributed in southeastern Oregon (Vasek 1966, Dealy 1990).

In areal extent, *J. occidentalis* has recently occupied more than 1,614,000 hectares (3,988,000 acres) in Washington, Oregon, Idaho, California, and Nevada, including 932,000 hectares (2,303,000 acres) in Oregon (Eddleman et. al.1994). In elevation, it has been shown to range from 1,450 to 2,000 meters (4,756 to 6,560 feet) on Steens Mountain Oregon (Miller and Rose 1995) to as low as 183 to 549 meters (600-1800 feet) along the Columbia River (Sowder and Mowat 1958).

History of J. occidentalis in Oregon

The earliest evidence of *J. occidentalis* in Oregon dates to 7000 to 4000 years ago. Climatic change and fire resulted in considerable variation in its presettlement extent (Miller and Wigand 1994). Before Euro-American settlement, stands were open, sparse, and savannah-like or confined to rocky areas with insufficient fine fuels to carry fire. Trees up to 1000 years old were usually found on steep, rocky slopes or in dissected topography where fire evidence is lacking or are found only in small patches (Miller and Rose 1995, West 1984). Griffiths observed only scattered stands of *J. occidentalis* in southeastern Oregon when touring the area on behalf of the Department of Agriculture in 1901 (Griffiths 1902).

The current expansion in both density and distribution began in the late 1800s (Young and Evans 1981, Eddleman 1987, Miller and Rose 1995). Even though the species is long-lived, less than 3% of the juniper woodlands in Oregon were characterized by trees more than 100 years old (USDI-BLM 1990). Reduced fire intervals have been a primary factor in the expansion. Overgrazing in the late 1800s and early 1900s reduced fire indirectly by reducing fine fuels. The effects of fire suppression became a major factor after World War II (Miller and Wigand 1994).

Other causes cited for the expansion include climate and other livestock effects, such as seed dissemination, reduced competition from forage species, and increases in shrub cover increasing the available microsites for establishment (Cottam and Stewart 1940). Mild climatic conditions and increased precipitation during the late 1800s and early 1900s were conducive to vigorous juniper growth (Fritts and Xiangdig 1986). A more recent factor has been the increase in the number of trees of reproductive age. Miller and Rose (1995) found a geometric increase in *J. occidentalis* on Steens Mountain beginning in the 1960s.

Old-growth characteristics

Old-growth research in the northwestern United States has been conducted primarily in heavily forested areas. Semi-arid woodlands have not generally been studied. What is known about old-growth juniper comes largely from anecdotal reports in the literature, noting the occurrence of presettlement trees in rimrock and other fire resistant areas. Descriptions of *J. occidentalis* on deeper, more productive soils and old-growth plant communities are completely lacking. In searching for sites with old trees suitable for cross-dating, Holmes et al. (1986) found that very old trees in the northern Great Basin and eastern California were generally widely spaced on steep, rocky, well-drained slopes with relatively sparse ground cover. They found that the oldest trees in these stands had relatively sparse crowns, massive and irregular tapering trunks, few but heavy branches, and generally nonsymmetrical appearances. In the pumice aeolian physiographic division, relatively extensive old stands have been observed, with tree canopy cover up to and exceeding 10% (Miller et al. 1995). Draft Natural Resources

Conservation Service (NRCS, formerly the Soil Conservation Service) ecological site descriptions for juniper south slopes and for juniper tablelands address plant communities, but do not address old-growth communities.

Stages leading to the development of old-growth *J. occidentalis* have been characterized by Miller et al.(1995). He describes a final transitional stage, the fully developed woodland, characterized by the following: tree canopy expansion is stabilized; leader growth on large trees is generally absent or limited to the upper canopy of dominant trees; canopy lift is present on productive sites; tree recruitment is nearly absent; small trees (less than 3 meters tall) show signs of severe stress including needle and branch mortality, increased presence of juvenile leaf growth especially towards the base of the canopies, and reduced ring growth; canopies of small trees have a cylindrical rather than inverted cone shape; and the live shrub layer is absent or nearly so with dead shrub skeletons commonly present on the site. Cover and composition of herbaceous vegetation in fully developed woodland is reported to be dependent on soils, land form, past and current disturbance (i.e. grazing), and tree density and cover (Miller et al. 1995).

In other plant communities, the characteristics of old-growth have been defined in numerous ways, from the scientific to the emotional. Kaufmann et al. (1992) noted that old-growth differs from other stages of forest development in providing unique, and often irreplaceable biological/ecological values, such as animal and plant habitat, biodiversity and genetic pools, and long-term climate records discernible through dendrochronological studies. Unique and sometimes irreplaceable social values cited include economic/extractive uses, recreation, and cultural/spiritual qualities.

Structural attributes of old-growth are reported to vary with forest type, climate, site conditions, and disturbance regime. Tree age alone is insufficient for assessing old-growth, even within a species. Structural attributes are more commonly described than functional attributes, due to relative ease of measurement (USDA Forest Service 1993).

The US Forest Service has defined old-growth forests generically as ecosystems distinguished by old trees and related structural attributes. Their definition states that old-growth encompasses the later stages of stand development that typically differ from earlier stages in a variety of characteristics which may include tree size, accumulations of large dead woody material, number of canopy layers, species composition, and ecosystem function (USDA Forest Service 1993).

Functionally, old-growth forest differs from mature (sic) forest in the complexity of its ecological interrelationships (Moir 1992). Old-growth ecosystems have been characterized as having a component of old trees that have a biochemistry of secondary metabolic products, some of which may provide high resistance to insects and disease. Relative to younger trees, the oldest trees have approached their maximum size and have nearly ceased height growth, and the tree crowns may be in various stages of decline. On average, the rate of production of new biomass is offset by mortality and respiration, and net productivity of the ecosystem approaches zero (Kaufmann et al. 1992). In general, old-growth detrital food webs are reported to be complex. Decay processes, some of which may involve nitrogen fixation, occur in snags, down logs, and dead portions of living trees. Arthropods and other microzoans occur in the forest litter and within decaying stems of old living trees, whose decay may involve nitrogen fixation. There may be mixed communities of cryptograms and associated invertebrates on tree branches and stems. The food web further includes fungal-small mammal relationships (Moir 1992).

The old-growth qualities listed above have not been directly applied to *J. occidentalis*. They may not always be appropriate given the relatively arid climate and nature of *J. occidentalis* old-growth stands. Some characterization has been done for other species of juniper. The USFS definition based on community structure has been applied to pinion-juniper by the Rocky Mountain Region (Mehl 1992) and the Southwestern Region (Popp et al. 1992) of the Forest Service. The resulting minimum structural attributes are shown in Table 1. These were designed to apply in various proportions of the two genera, even to solely juniper (Mehl 1992).

Popp et al. (1992) also included reduced minimum attributes for low condition pinion-juniper old-growth. The supplemental narrative description of pinion-juniper old-growth produced by the USFS Rocky Mountain Region includes the following:

> "Stands may consist of all ages or one age. Dominant trees are often 400 years old. Trees 800 to 1000 years old have been recorded. The trees can be single

Table 1 Old-growth pinion-juniper attributes described by Mehl (1992) and Popp et al. (1992).

PARAMETER	AMOUNT
Live trees	
Trees per acre	30
Diameter at root collar	12 inches, with variations in diameter
Age	200 years
Decadence present	Yes, as dead, broken, or deformed tops and/or bole or root rot (Mehl only)
Number of tree canopies	Single story
Total canopy cover	35%
Other	Upper canopy trees are slow growing (Mehl), variation in tree diameter (Mehl), basal area of 23 square feet/acre (Popp)
Standing dead trees	
Number per acre	1
Diameter at root collar	10 inches
Down dead trees - 10 foot long segments (Popp) or length not specified (Mehl)	
Pieces	2 per acre
Diameter	10 inches

stemmed or have a sprawling multi-stemmed character. A few stands may have closed canopies with single or both tree species, with little or no understory, but most stands are open-grown with widely scattered trees of one or both species with a wide variety of understory vegetation.

The pinyon-juniper woodland is shade intolerant. It is the climax cover type remaining on the site until disturbed by fire...

An old-growth pinyon-juniper stand would be fairly open grown and contain a cohort of dominant old slow growing trees with little or no understory of grass or shrubs. The old trees would be single to multi-stemmed and shorter than the tree species at higher elevation. Being open grown it would be hard to distinguish if more than one tree canopy exists. The old trees would vary in diameter, some would have dead branches/limbs including even part of the stem. There would be an occasional dead standing tree. Down dead material would exist and for quite a while as the climate is semiarid. However a significant amount of the dead material would also exist on the live trees" (Mehl 1992).

The structural definition above included the presence of woody debris. Procedures for further classifying woody debris in juniper woodlands have not been reported. Several similar schemes have been applied to other old-growth, particularly Douglas-fir forests (Franklin et al. 1981, Maser et al. 1988, Maser and Trappe 1984, Sollins 1982). Both the stages and rate of disintegration varied by species and other factors (Franklin et al.1981).

Classifications of standing woody debris have typically included five stages, as shown in Figure 1. For Douglas-fir, these stages included the characteristics shown in Table 2, plus several others that cannot be related to this study (after Maser et al. 1988). This classification did not include dead limbs on live trees, which can be a significant portion of the woody debris to be found in standing trees. Like the old-growth definition, these classifications depended on structural attributes. Functional characteristics of the debris, such as cavities for nesting habitat and nutrient cycling, were not included in the categorization.

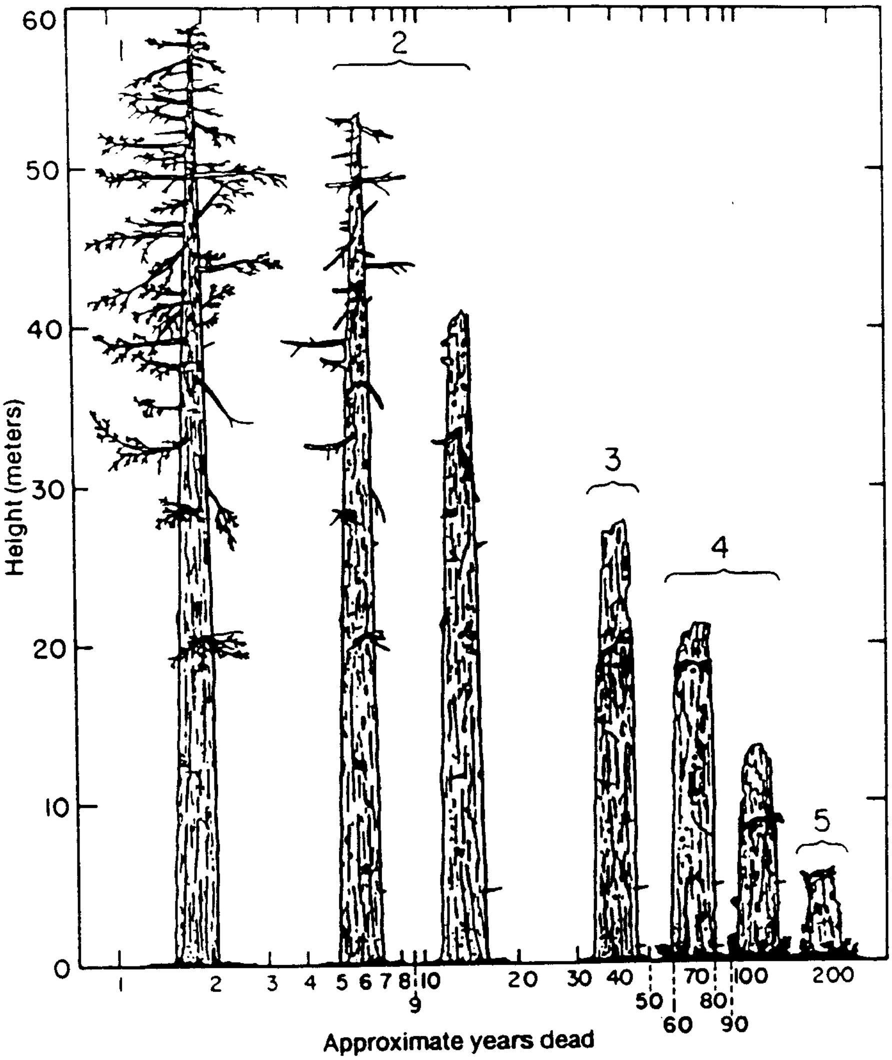


Figure 1 Decay classification of standing woody debris for Douglas-fir (from Franklin et al. 1981).

Table 2 Decay classification of standing woody debris.

Snag Characteristic	Decay Class I	II	III	IV	V
Limbs and branches	All present	Few limbs, no fine branches	Only limb stubs	Few or no stubs	None
Top	Pointed	Broken	Broken	Broken	Broken
Top diameter	---------- Increases at decreasing rate ----------				
Height	---------- Decreases at decreasing rate ----------				
Bark remaining	100%	Varies	Varies	Varies	Varies
Sapwood	Intact, sound, hard, original color, incipient decay	Sloughs, fibrous, firm to soft, advanced decay	Sloughs, fibrous, soft	Sloughs, cubical, soft	Gone

Table 3 Decay classification of fallen woody debris.

Decay Class	Attribute: Bark	Structural Integrity	Branch System
I	Intact	Sound	Current year's twigs present
II	Mostly Intact	Sapwood somewhat decayed, heartwood mostly sound	Larger twigs present, branch system entire
III	Sloughing or absent	Heartwood mostly sound, supports own weight	Heartwood rotten, not weight bearing, branch stubs pull out
IV	Detached or absent	Heartwood rotten, not weight bearing, branch stubs pull out	Branch stubs present, shorter than log diameter
V	Absent	None	Absent

The rating schemes established for downed debris also have five stages. Sollins's (1982) classification scheme for fallen large-diameter Douglas-fir included five attributes. Three shown in Table 3 may be applicable to *J. occidentalis*. Attributes related to roots invading the debris and growth of trees rooted in the fallen log are not included as these phenomena have not been observed in juniper debris. Figure 2 illustrates decay stages for fallen Douglas-fir debris (from Maser and Trappe 1984).

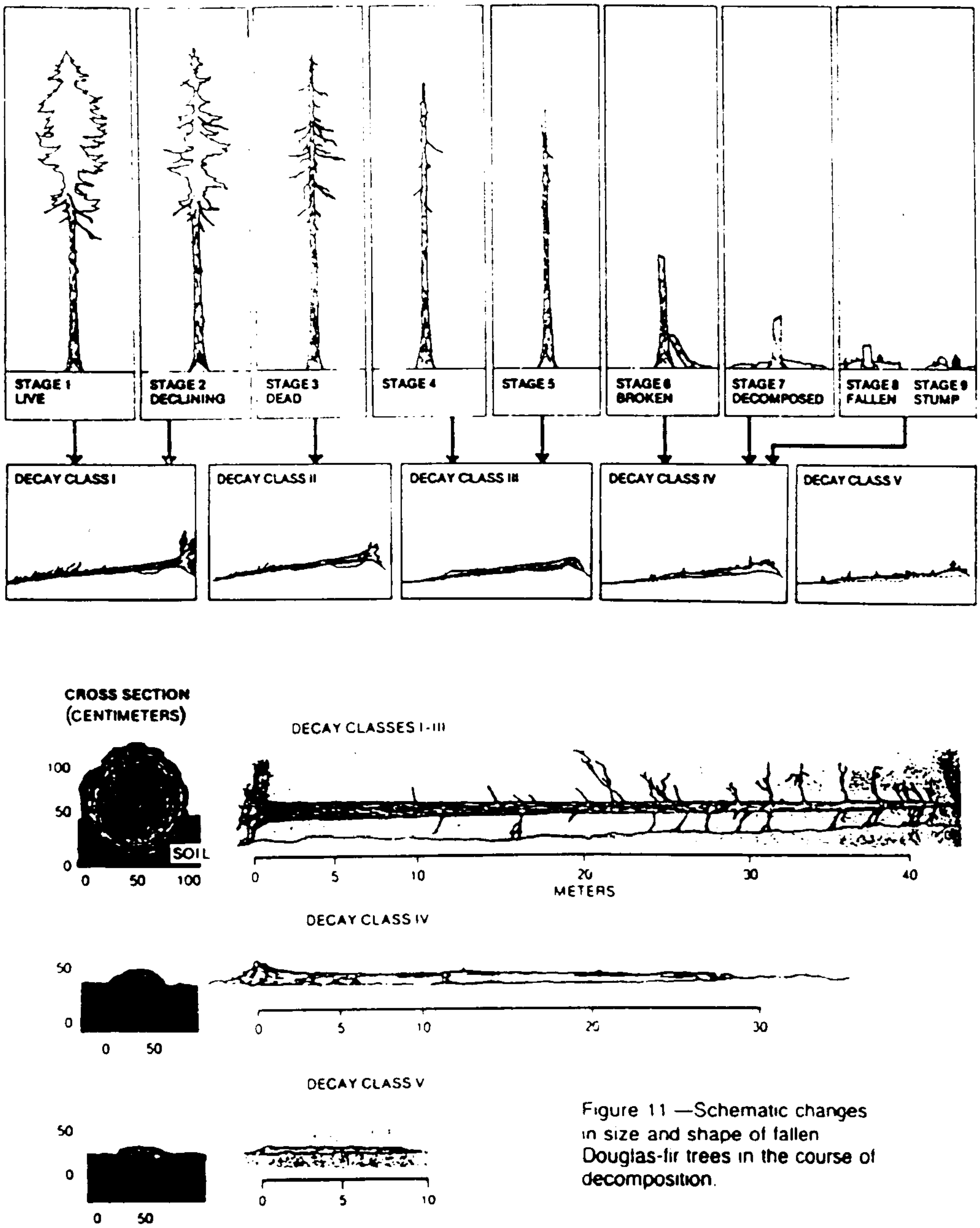


Figure 2 Decay stages for fallen Douglas-fir debris (from Maser and Trappe 1984).

STUDY AREA

The study sites were located in central Oregon, in eastern Deschutes County and northern Lake County. They were within the area that Anderson (1956) termed the pumice aeolian physiographic division of the ecological provinces of Oregon. Seven sites were located up to sixty miles apart in three areas.

The Connley Hills are located about 14 miles west of Christmas Valley, Oregon. Sites were established on the steep western (Connley Hills West) and steep eastern (Connley Hills East) slopes. Channer-sized rock was the predominant ground surface. Anthropogenic disturbance appears to be minimal in this area due to remoteness from a water supply.

Green Mountain lies about ten miles north of Christmas Valley. Slopes of Green Mountain are gradual. Rocky outcrops are particularly prevalent on the north side. Three study sites were located at Green Mountain. On the north side, one site (Green Mountain North-Mounds) was established on rock outcrops, and another (Green Mountain North-Interspaces) between the outcrops. The third site (Green Mountain South), located on the south side, did not include rock outcrops. This area showed the most disturbance of the three. Cattle grazing had recently occurred at the north interspace site and at the south site.

The Horse Ridge and Badlands sites were located about fifteen miles east of Bend. One of these sites (Horse Ridge North) was on the north facing slopes of Horse Ridge. Plots were located along the apex of three adjacent convex ribs. To the north, the other site (Badlands) was situated in an area referred to as the Badlands. The juniper trees and most other vegetation occur on basaltic lava mounds that punctuated nearly barren sandy interspaces. (See Chitwood (1994) for a discussion of these inflated lava "tumuli".) Sampling was conducted in the Badlands both on the mounds and in the interspaces. Since the interspace plots did not contain any trees, the interspace site was not included in the analysis or in this report. Evidence of disturbance was minimal at both Horse Ridge North and Badlands, although a number of large trees had been cut and removed from the lava mounds. None of the old stumps were located within study plots, however. Site codes used throughout the remainder of this report and other information on the sites are shown in Table 4.

The climate in the study area has been characteristic of the northern Great Basin. Precipitation has averaged 8 to 11 inches per year, predominantly as winter snow and spring rain. The Natural Resource Conservation Service (NRCS) site description for the Shallow Pumice Hills - 10-12" precipitation zone at Horse Ridge notes a frigid soil temperature regime, a frost free period of 50 to 90 days, and air temperatures averaging 46 degrees Fahrenheit annually, with extremes ranging from -25 to 100 degrees. The Gosney and Deskamp soils characterizing the Badlands have a mesic thermal regime. The other sites have frigid soil regimes. Optimum growing seasons have ranged from late March or early April through June or early July.

Official soil surveys have not been completed in most of the study areas. However, soils at all sites were derived from volcanic ash deposits of aeolian origin. The soil description for the Badlands site indicates a complex of Lithic Torripsamments (typically 14 inches to bedrock), Vitritorrandic Haploxerolls (typically 32 inches to bedrock), and rock outcrop. Soil on the rock outcrops in the Badlands had accumulated in shallow rock depressions. At the Green Mountain North-Mounds site, soil was similarly contained in rock depressions but was generally deeper.

Table 4 Study site characteristics. Topographic data are presented as the mean value for the nine plots at each site. Soils data is based on one or more soil pits dug at each site. "n.d." indicates no data available.

Area and site	Connley Hills East	Connley Hills West	Horse Ridge North	Bad-lands	Green Mtn. North mounds	Green Mtn. North interspaces	Green Mtn. South
Code	CHE	CHW	HRN	BAD	GMNm	GMNi	GMS
Topography							
Slope (%)	31	42	17	0	7	3	2
Aspect (°)	95	261	14	0	48	123	174
Elevation (m)	1551	1557	1266	1177	1517	1515	1477
Terrain	steep east slope	steep west slope	north slopes	lava mounds	lava mounds	shallow slope	shallow slope
Soils							
Texture[(1)]	loamy sand	loamy sand	loamy sand	sandy loam	loamy sand	loamy sand	loamy sand
Depth	n.d.	67+	60	0+	0 to 42	85	70+
Surface horizon pH	n.d.	n.d.	6.9	6.4	n.d	6.4	6.4

Notes

(1) Based on core samples collected during the project.

METHODS

Sampling methods

Three 1000 meter transects were established arbitrarily within each site, without preconceived bias. Three sampling plots were placed on each transect (9 plots per site) except at Green Mountain North. Plot locations were selected arbitrarily, but with plots ranging from the first third to the last third of each transect. Plot centers were located by a blind toss of a meter pole. At Green Mountain North, six plots were established along each transect, three each on and off of the rocky outcrops. The interspace plots were located away from the edges of the mounds. At the Badlands site, three lava mounds along each transect were selected. Not more than two of the three plots were located on mounds in sequence. Plots were set up on each mound selected and on the interspace adjacent to each mound. Since no trees were found in the interspaces, the interspace plots are not discussed further.

Measurements taken and procedures used at each plot are shown in Table 5. Tree populations were surveyed within a circular plot. Live trees, standing dead trees, and fallen trees were surveyed. Only trees over 1 meter tall were counted as live trees. Plot diameters were generally 20 meters. When this size plot would have resulted in more than about 25 trees being included, the diameter was decreased to 15 meters to reduce the variance in tree counts between plots. Some mounds at the Badlands site were less than 15 meters wide. For those mounds, a noncircular area on top of the mound was surveyed.

Tree cores were collected from a portion of the plots. Within those plots, an attempt was made to sample all trees. Problems with heartwood rot occurred in most trees over about 250 years old. As a result, complete cores were obtained for only 26 trees and nearly complete cores were obtained for an additional 95 trees.

Three 30 meter line transects were laid out at each plot for shrub, herbaceous plant, and ground cover assessments. One line was placed through the center of the circular plot, along the terrain contour. The other lines were placed parallel to and 15

Table 5 Field measurements and techniques.

PARAMETER	DESCRIPTION AND MEASUREMENT TECHNIQUE
Live trees (greater than 1 m high)	
Age class	Visual estimation of age • postsettlement -trees with conical form and obvious terminal and lateral leader growth • presettlement - trees with rounded tops and little leader growth. Trees may have crown lift, deeply furrowed or stringy bark, and large trunk diameters for the height of the tree.
Form	Visual placement into one of four categories, based on fullness of canopy: • 1 - full (greater than 90% of canopy live), • 2 - half (50 to 90% of canopy live), • 3 - limited (at least 10% but less than 50% of canopy live), • 4 - very limited (under 10% of canopy live).
Height	Scaled to the nearest half meter using a three meter long calibrated pole.
Diameter	Trunk diameter at 30 cm above ground level, read using a pole calibrated in 10 cm increments.
Cover	Intercept on 3 lines of 30 m per plot
Canopy dimensions	Foliage spread measured along and perpendicular to the direction of maximum foliage spread. (Note: this technique generally overstates canopy area on trees which do not have a full canopy.)
Live trees less than 1 meter high	Trees between 15 cm and 1 m were tallied in each plot. Trees less than 15 cm high were counted only if they occurred within the shrub belt transects.
Tree age	Coring of trees and comparison of cores to climatic masters. Most of the cores were incomplete due to heartwood rot.
Standing dead trees (greater than 25 cm diameter)	
Height	Scaled to the nearest half meter using a three meter calibrated pole.
Diameter	Trunk diameter at 30 cm above ground level, read using a pole calibrated in 10 cm increments.

Table 5 Continued.

Form	Visual placement into one of five categories based on extent of deterioration: • S1 - fine branches present, • S2 - parts of primary branches left, • S3 - no branches remaining and bole height reduced by up to half, • S4 - no branches remaining and bole height reduced by more than half, • S5 - only short stump remaining.
Fallen woody debris (pieces at least 3.3 m long)	
Length	Measured with tape measure
Diameter	Measured with tape measure 30 cm above apparent ground level.
Form	Visual placement into one of five categories based on extent of deterioration: • D1 - bark intact and twigs present, • D2 - some bark and branches present, bole elevated off ground by branch parts, • D3 - remaining branches reduced to stubs, bole elevated off ground, • D4 - bole on ground, wood rotten but structural integrity remains, • D5 - wood mound, no structural integrity
Shrubs, by species, and juvenile junipers (less than 15 cm height)	
Density	Counted in 2 by 30 m belt transects by each of the following conditions: at least 50% of shrub live, live with less than 50% of shrub live, dead.
Cover	Line intercept of live shrub and of dead shrubs on 30 m transects.
Herbaceous and other ground cover	
Herbaceous cover by species	% cover by species within plot frame, visually estimated to nearest per cent, if less than 10%, or nearest 5%, if 10% or greater. Shrubs and trees not included.
Other ground cover	% ground cover within plot frames, visually estimated to nearest per cent, if less than 10%, or nearest 5%, if 10% or greater for each of the following: rock, bare ground, cryptogamic crust, juniper litter, other litter.

Table 5 Continued.

Plot frame location	Frame location with respect to juniper trees noted as interspace, under canopy, or in the transition zone at the edge of the canopy.
Species richness	All species present in each plot listed
Environmental parameters measured in each plot	
Slope	clinometer
Elevation	altimeter (topographic map if altimeter unavailable)
Aspect	compass
Soil description	Bulk samples collected for gravimetric texture analysis.
	Profile descriptions done in field.
	Water characteristic curves.
Fire history	Fire scars noted, if any

meters on either side of the first, where possible. At some plots on rocky mounds, adjustments in position had to be made to ensure that the entire line was contained on the mound. Measurements of shrub and small juniper (15 to 100 centimeter) density were made in a 2 meter wide belt transect centered on each 30 meter line. Along the line 0.2 square meter (40 by 50 centimeters) plot frames were place at 3 meter intervals for herbaceous species and other ground cover assessment (30 frames per plot). Shrub and tree cover were measured on the line transect.

One or more soil pits were dug at each site for soil analysis. Texture was measured on bulk samples at the Eastern Oregon Agricultural Research Center laboratory using the hydrometer method of particle size analysis (Gee and Bauder 1986). Additional surface horizon samples were collected using a double-ring bulk sampler. These samples were analyzed for moisture release properties using a ceramic pressure plate extraction technique at the Oregon State University Crop and Soil Science Department Physical Characterization Laboratory. Conditions at some sites did not allow for successful collection of samples with the double-ring bulk sampler.

Data analysis methods

Several different methods of data analysis were used. Data were reduced to means and standard errors by site. Analysis of variance and regression analysis were used to test for relationships between understory attributes and abiotic or tree conditions. Analysis of variance was also used to test for relationships between tree age and other tree parameters. Studentized t-tests were used to compare some plot attributes within sites. A significance level of 0.05 was used for all of these analyses. Several different types of multivariate analyses were used to investigate within and between site variation and to identify indicator species. Analyses of variance and regression analyses were done using The SAS System for Windows, Version 6.12, while t-tests were done in Microsoft Excel Version 7.0. Multivariate analyses were done using PC-ORD for Windows, Version 3.03 (McCune and Mefford 1995).

Since management of old-growth woodlands first requires recognition of the old-growth condition, it would be useful to be able to predict tree age from other tree parameters. Tree age prediction was specifically needed in this study to compare these woodlands to the pinion-juniper old-growth definition. An attempt was made to sample all trees in selected plots. Complete cores were obtained for only a small sample (n=26) of trees in the plots, partly because of the predominance of heartwood rot in trees over 200 years old. Stepwise regression was used to look for significant relationships between age and the individual parameters height, diameter, basal area, canopy area, and tree form. Analysis of variance was used to test combinations of variables.

Several types of multivariate analysis were used. Data were first reduced into two matrices. A species cover matrix contained, for each plot, the percent cover of each understory species found in the project and the tree density. This measure of tree importance was used because it is the most accurate of the measurements taken and because linear regressions had shown it to have better correlation with environmental parameters than the other tree parameters studied. To reduce the high skew (5.0) and coefficient of variation (460%) in the totals of species, several adjustments were made. Species occurring in fewer than five percent of the plots (fewer than 4 plots) were deleted, leaving 56 species in the matrix. Juniper density data was log transformed. Species cover data was transformed as follows:

transformed value = *log (original value + minimum non-zero cover value in matrix) - log (minimum non-zero cover value in matrix).*

This transformation allowed initial values of zero to remain zero. The second matrix contained plot environmental data and other plot parameters. This matrix contained slope (degrees), heat load on a scale of zero to one [1 - cos (aspect angle - 45)/2], elevation, species richness, total understory plant cover, tree density, tree basal area, tree canopy area, and ground cover by rock, bare ground, moss, crust, juniper litter, and other litter for each plot.

Hierarchical agglomerative cluster analysis was used to produce a dendrogram grouping the 63 plots. This analysis was done using Euclidian distance and Ward's method as described by Orloci (1967).

The Multi-Response Permutation Procedure (MRPP) tests whether there is a significant difference between two or more groups, by comparing the average within-group distance to the average that is obtained by a randomized assignment of the same data points to groups. It is a non-parametric procedure that avoids assumptions of data normality and equality of variance. The procedure was run using a site indicator as the grouping variable, to test for significant differences between any of the sites. Runs were also made to test for differences between sites in the same area and for the difference between areas. The Euclidian distance measure was used.

The differences between sites were explored further using Indicator Species Analysis (Dufrene and Legendre 1997). This technique can be used to evaluate which species best distinguish individual sites. Indicator Species Analysis calculated an indicator value for each species at each site. This value is the product of relative abundance, the abundance of the species at the site relative to its abundance in all sites, times relative frequency, the proportion of sample units (plots) in the site that contain the species. The highest indicator value for each species is tested for significance using a Monte Carlo technique. Indicator species were analyzed for the seven sites using the untransformed species matrix.

Ordination was done using the Nonmetric Multidimensional Scaling (NMS) technique (Kruskal 1964 and Mather 1976) to show the arrangement of the plots in species space and allow comparison of the within-site and between-site distribution. This iterative technique ordinates based on ranked distances between sites, avoiding the assumption of data normality. "Stress" is used in NMS as a measure of departure from monotonicity in the relationship between the distance between plots in the original many-dimensional space and the distance in the reduced-dimensional space. An initial run was made using six dimensional space, Sorensen distance, and 100 iterations. Plots of stress versus iteration were examined for instability and to find the lowest axis at which the reduction in stress gained by adding another axis was small. A final run of 100 iterations was made using three axes. Monte Carlo simulation was included as a check on whether a similar final stress could have been obtained by chance. Overlays of individual species, plant functional types, and environmental variables on the resulting ordination allowed for an examination of the correlation between these variables and the ordination axes.

RESULTS

Data summaries

Cover data, including plant and other ground cover, and species richness and diversity, are summarized by site and across sites in Table 6. See Appendix 1 for a listing of all species found at each site and the species codes used in this discussion.

Herbaceous plant cover ranged from 5 to 14%, with an average of 9% among all sites. Including shrub cover, understory cover ranged from 7 to 15%, with an average of 12%. Shrub cover was negligible at the Connley Hills sites. The Horse Ridge and Badlands sites had the greatest shrub diversity (6 and 5 species respectively) and cover (6 and 10% respectively).

Juniper cover averaged 23%. The Horse Ridge/Badlands area had low tree cover (18 and 11% respectively). The greatest difference within an area was seen at Connley Hills. East slope plots averaged 33% (S.E. = 9%) cover, while west slope plots had only 14% (S.E. = 7%) cover. At Green Mountain, the north side interspaces had lower tree cover than the other two sites.

The most abundant shrubs were *Artemisia tridentata* ssp. *vaseyana*, *Chrysothamnus nauseosus* (Pall.) Britt, and C. *viscidiflorus* (Hook.) Nutt. (Table 7). *Purshia tridentata* (Pursh) DC. and *Tetradymia canescens* DC. also occurred at more than one site. The Horse Ridge North and Badlands sites had the highest shrub density and the highest proportion of shrubs in healthy condition, based on the proportion of shrubs with mostly live branches. A high proportion (68%) of the small shrub population at Connley Hills East was dead. The proportion of dead shrubs on the west slopes (29%) was closer to the project average (24%).

Bare ground ranged from 5% to 63%, with an average of 32%, while the combination of bare ground and rock cover had a much narrower range, from 51% to 69%. The texture of the uppermost soil horizon was sandy loam (6 sites) to loamy sand

Table 6. Plant cover, including selected species, and species richness and diversity. Cover is given in percent.

Type of Cover or Richness	CHE			CHW			HRN			BAD		
	mean	+/-	s.e.	mean	+/-	s.e.	mean	+/-	s.e.	mean	+/-	s.e.
HERBACEOUS PLANT COVER												
Total understory cover	7	+/-	3	12	+/-	3	11	+/-	2	14	+/-	4
Herbaceous plants	7	+/-	3	11	+/-	3	6	+/-	1	5	+/-	1
Perennial grasses	5	+/-	2	9	+/-	3	5	+/-	1	3	+/-	1
Perennial forbs	1	+/-	2	1	+/-	1	1	+/-	0	2	+/-	1
Annual grasses	0.0	+/-	0.0	0.1	+/-	0.1	0.0	+/-	0.0	0.0	+/-	0.0
Annual forbs	0.2	+/-	0.2	0.5	+/-	0.4	0.1	+/-	0.1	0.1	+/-	0.1
Common perennial grasses												
Agropyron spicatum	1.6	+/-	0.9	6.9	+/-	2.8	0.9	+/-	0.5	1.0	+/-	0.8
Festuca idahoensis	1.8	+/-	1.6	0.5	+/-	0.5	3.0	+/-	1.3	0.9	+/-	0.5
Koelaria cristata	0.4	+/-	0.3	0.9	+/-	0.6	0.4	+/-	0.2	0.0	+/-	0.0
Poa sandbergii	0.5	+/-	0.3	0.6	+/-	0.2	0.5	+/-	0.3	0.6	+/-	0.6
Sitanion hystrix	0.1	+/-	0.1	0.0	+/-	0.0	0.0	+/-	0.1	0.2	+/-	0.2
Stipa thurberiana	0.9	+/-	0.8	0.5	+/-	0.4	0.0	+/-	0.1	0.1	+/-	0.2
TREE AND SHRUB COVER												
J. occidentalis	33	+/-	9	14	+/-	7	18	+/-	6	11	+/-	5
Total shrub cover	0	+/-	0	1	+/-	1	6	+/-	2	10	+/-	4
Artemisia tridentata	0.0	+/-	0.0	0.6	+/-	1.4	3.8	+/-	1.6	8.2	+/-	3.2
Chryosothamnus nauseosus	0.0	+/-	0.0	0.0	+/-	0.1	0.2	+/-	0.4	0.6	+/-	1.2
C. viscidiflorus	0.0	+/-	0.0	0.1	+/-	0.3	1.1	+/-	0.8	0.5	+/-	0.8
Purshia tridentata	0.0	+/-	0.0	0.0	+/-	0.0	0.2	+/-	0.4	0.5	+/-	1.1
Tetradymia canescens	0.0	+/-	0.0	0.1	+/-	0.3	0.1	+/-	0.2	0.0	+/-	0.1
OTHER GROUND COVER												
Total other ground cover	93	+/-	3	89	+/-	5	94	+/-	2	96	+/-	1
Rock	39	+/-	5	64	+/-	8	15	+/-	8	37	+/-	12
Bare ground	18	+/-	8	5	+/-	3	46	+/-	8	18	+/-	9
Cryptogamic crust	1	+/-	1	1	+/-	3	1	+/-	1	1	+/-	1
Moss	9	+/-	6	1	+/-	1	10	+/-	3	11	+/-	4
Juniper litter	22	+/-	6	13	+/-	5	15	+/-	5	23	+/-	6
Other litter	5	+/-	2	4	+/-	3	8	+/-	2	6	+/-	2
SPECIES RICHNESS AND DIVERSITY												
Herbaceous species/plot	23	+/-	4	19	+/-	4	27	+/-	7	16	+/-	4
Herbaceous species/site	47			36			52			38		
Shrub species/plot	0	+/-	0	1	+/-	1	3	+/-	1	3	+/-	1
Shrub species/site	1			4			6			5		
Understory species/plot	23	+/-	4	20	+/-	5	30	+/-	6	19	+/-	4
Site species richness	49			41			58			44		
Simpson index	6.3			3.0			5.0			2.9		
Shannon-Wiener index	9.6			6.5			8.2			5.4		

Table 6. continued.

Type of Cover or Richness	GMNm mean +/- s.e.	GMNi mean +/- s.e.	GMS mean +/- s.e.	All sites mean +/- s.e.
HERBACEOUS PLANT COVER				
Total understory cover	12 +/- 3	12 +/- 4	15 +/- 3	12 +/- 1
Herbaceous plants	8 +/- 2	9 +/- 3	14 +/- 3	9 +/- 1
Perennial grasses	7 +/- 2	8 +/- 3	12 +/- 2	7 +/- 1
Perennial forbs	1 +/- 1	1 +/- 0	1 +/- 1	1 +/- 0
Annual grasses	0.0 +/- 0.0	0.0 +/- 0.0	0.0 +/- 0.0	0.0 +/- 0.0
Annual forbs	0.1 +/- 0.0	0.1 +/- 0.1	0.0 +/- 0.0	0.2 +/- 0.1
Common perennial grasses				
Agropyron spicatum	0.5 +/- 0.5	0.1 +/- 0.3	0.7 +/- 0.6	1.7 +/- 0.9
Festuca idahoensis	5.3 +/- 2.2	7.2 +/- 3.0	9.9 +/- 2.4	4.1 +/- 1.0
Koelaria cristata	0.2 +/- 0.2	0.1 +/- 0.1	0.2 +/- 0.2	0.3 +/- 0.2
Poa sandbergii	0.8 +/- 0.6	0.4 +/- 0.3	0.4 +/- 0.4	0.6 +/- 0.1
Sitanion hystrix	0.2 +/- 0.2	0.3 +/- 0.2	0.3 +/- 0.2	0.2 +/- 0.1
Stipa thurberiana	0.0 +/- 0.0	0.1 +/- 0.1	0.9 +/- 0.6	0.4 +/- 0.3
TREE AND SHRUB COVER				
J. occidentalis	32 +/- 9	21 +/- 7	31 +/- 10	23 +/- 2
Total shrub cover	4 +/- 3	3 +/- 2	1 +/- 1	3 +/- 1
Artemisia tridentata	3.4 +/- 2.9	3.0 +/- 1.8	0.7 +/- 0.7	2.8 +/- 1.1
Chryosothamnus nauseosus	0.2 +/- 0.5	0.0 +/- 0.0	0.0 +/- 0.0	0.2 +/- 0.4
C. viscidiflorus	0.1 +/- 0.3	0.1 +/- 0.3	0.0 +/- 0.1	0.3 +/- 0.3
Purshia tridentata	0.0 +/- 0.0	0.0 +/- 0.0	0.0 +/- 0.0	0.1 +/- 0.4
Tetradymia canescens	0.2 +/- 0.4	0.0 +/- 0.0	0.1 +/- 0.1	0.1 +/- 0.2
OTHER GROUND COVER				
Total other ground cover	92 +/- 2	90 +/- 4	84 +/- 5	91 +/- 2
Rock	27 +/- 11	2 +/- 2	3 +/- 4	27 +/- 3
Bare ground	24 +/- 11	63 +/- 9	49 +/- 9	32 +/- 2
Cryptogamic crust	1 +/- 1	1 +/- 1	1 +/- 0	1 +/- 1
Moss	12 +/- 6	5 +/- 4	3 +/- 2	7 +/- 2
Juniper litter	23 +/- 5	13 +/- 6	23 +/- 9	19 +/- 2
Other litter	4 +/- 2	6 +/- 4	5 +/- 2	6 +/- 1
SPECIES RICHNESS AND DIVERSITY				
Herbaceous species/plot	22 +/- 3	19 +/- 4	17 +/- 3	
Herbaceous species/site	47	40	35	82 total
Shrub species/plot	2 +/- 1	1 +/- 1	1 +/- 1	
Shrub species/site	5	3	4	7 total
Understory species/plot	23 +/- 3	21 +/- 4	19 +/- 3	
Site species richness	53	44	40	89 total
Simpson index	3.7	2.5	2.1	
Shannon-Wiener index	6.6	4.4	4.3	

Table 7. Woody plant densities and other tree attributes. Densities are given in number/ha.

SHRUB OR TREE	CHE			CHW			HRN		
	mean	+/-	s.e.	mean	+/-	s.e.	mean	+/-	s.e.
DENSITIES OF MOST ABUNDANT SHRUBS (BY CONDITION)									
A. tridentata - live	68	+/-	114	259	+/-	534	2179	+/-	967
A. tridentata - half live	25	+/-	40	25	+/-	40	593	+/-	245
A. tridentata - dead	210	+/-	253	210	+/-	138	623	+/-	410
C. nauseosus - live	0	+/-	0	56	+/-	73	93	+/-	133
C. nauseosus - half live	0	+/-	0	0	+/-	0	0	+/-	0
C. nauseosus - dead	0	+/-	0	0	+/-	0	6	+/-	19
C. viscidiflorus - live	6	+/-	19	62	+/-	85	858	+/-	702
C. viscidiflorus - half live	0	+/-	0	6	+/-	19	31	+/-	40
C. viscidiflorus - dead	0	+/-	0	0	+/-	0	25	+/-	40
DENSITY OF ALL SHRUBS									
Total live	74	+/-	111	543	+/-	579	3716	+/-	711
Total half live	25	+/-	40	31	+/-	49	667	+/-	295
Total dead	210	+/-	253	235	+/-	138	685	+/-	388
Total live and half live	99	+/-	138	574	+/-	568	4383	+/-	806
All shrub total	309	+/-	359	809	+/-	645	5068	+/-	1111
Live shrubs as % of total	24%			67%			73%		
Dead shrubs as % of total	68%			29%			14%		
JUNIPER DENSITIES									
Live (at least 1m tall) trees	302	+/-	96	114	+/-	43	258	+/-	79
REGENERATION									
Seedlings (< 15 cm tall)	0	+/-	0	86	+/-	155	6	+/-	19
Juvenile (15 - 100 cm tall)	2	+/-	5	3	+/-	4	13	+/-	11
DETRITUS									
Fallen dead pieces	17	+/-	42	11	+/-	8	3	+/-	6
Standing dead trees	22	+/-	19	13	+/-	14	9	+/-	12
OTHER LIVE (at least 1m tall) TREE ATTRIBUTES									
Basal area (m2/ha)	21	+/-	4	18	+/-	4	22	+/-	2
Mean height (m)	5	+/-	1	4	+/-	1	4	+/-	0
Mean diameter (cm)	28	+/-	5	43	+/-	11	30	+/-	6
% with "Pre" form	77%			78%			76%		
JUNIPER RATIOS									
Live trees : 15 - 100 cm trees	192			43			21		
Live trees : fallen dead pieces	17			11			82		
Live trees : standing dead trees	14			9			27		
Live trees : dead trees or pieces	8			5			21		
Height : diameter	17			10			13		

Table 7. continued.

SHRUB OR TREE	BAD			GMNM			GMNI		
	mean	+/-	s.e.	mean	+/-	s.e.	mean	+/-	s.e.
DENSITIES OF MOST ABUNDANT SHRUBS (BY CONDITION)									
A. tridentata - live	6580	+/-	3296	1488	+/-	599	1210	+/-	523
A. tridentata - half live	1290	+/-	866	352	+/-	256	543	+/-	211
A. tridentata - dead	2278	+/-	1156	833	+/-	571	840	+/-	688
C. nauseosus - live	401	+/-	407	74	+/-	79	19	+/-	28
C. nauseosus - half live	99	+/-	186	31	+/-	74	0	+/-	0
C. nauseosus - dead	93	+/-	133	6	+/-	19	0	+/-	0
C. viscidiflorus - live	438	+/-	380	198	+/-	293	148	+/-	155
C. viscidiflorus - half live	6	+/-	19	0	+/-	0	0	+/-	0
C. viscidiflorus - dead	12	+/-	24	0	+/-	0	0	+/-	0
DENSITY OF ALL SHRUBS									
Total live	7654	+/-	3598	2025	+/-	849	1444	+/-	565
Total half live	1414	+/-	1027	383	+/-	312	543	+/-	211
Total dead	2389	+/-	1210	846	+/-	564	840	+/-	688
Total live and half live	9068	+/-	3983	2407	+/-	836	1988	+/-	684
All Shrub Total	11457	+/-	4922	3253	+/-	1212	2827	+/-	668
Live shrubs as % of total	67%			62%			51%		
Dead shrubs as % of total	21%			26%			30%		
JUNIPER DENSITIES									
Live (at least 1m tall) trees	192	+/-	61	322	+/-	121	102	+/-	47
REGENERATION									
Seedlings (< 15 cm tall)	37	+/-	56	56	+/-	167	25	+/-	40
Juvenile (15 - 100 cm tall)	22	+/-	24	9	+/-	16	47	+/-	40
DETRITUS									
Fallen dead trees	3	+/-	7	1	+/-	3	0	+/-	0
Standing dead trees	19	+/-	19	21	+/-	19	0	+/-	0
OTHER LIVE (at least 1m tall) TREE ATTRIBUTES									
Basal area (m2/ha)	22	+/-	7	39	+/-	11	20	+/-	7
Mean height (m)	4	+/-	1	5	+/-	0	6	+/-	1
Mean diameter (cm)	32	+/-	4	36	+/-	6	47	+/-	11
% with "Pre" form	85%			75%			65%		
JUNIPER RATIOS									
Live trees : 15 - 100 cm trees	9			34			2		
Live trees : fallen dead pieces	58			365			n.a.		
Live trees : standing dead trees	10			15			n.a.		
Live trees : dead trees or pieces	9			15			n.a.		
Height : diameter	14			13			14		

Table 7. continued.

SHRUB OR TREE	GMS			All sites		
	mean	+/-	s.e.	mean	+/-	s.e.
DENSITIES OF MOST ABUNDANT SHRUBS (BY CONDITION)						
A. tridentata - live	556	+/-	237	1763	+/-	1093
A. tridentata - half live	302	+/-	256	447	+/-	278
A. tridentata - dead	883	+/-	598	840	+/-	333
C. nauseosus - live	19	+/-	56	94	+/-	137
C. nauseosus - half live	6	+/-	19	19	+/-	70
C. nauseosus - dead	0	+/-	0	15	+/-	49
C. viscidiflorus - live	290	+/-	200	286	+/-	229
C. viscidiflorus - half live	12	+/-	37	8	+/-	17
C. viscidiflorus - dead	0	+/-	0	5	+/-	16
DENSITY OF ALL SHRUBS						
Total live	957	+/-	354	2345	+/-	1185
Total half live	327	+/-	244	484	+/-	334
Total dead	883	+/-	598	869	+/-	351
Total live and half live	1284	+/-	343	2829	+/-	1317
All Shrub Total	2167	+/-	739	3698	+/-	1589
Live shrubs as % of total	44%			63%		
Dead shrubs as % of total	41%			24%		
JUNIPER DENSITIES						
Live (at least 1m tall) trees	175	+/-	50	209	+/-	29
REGENERATION						
Seedlings (< 15 cm tall)	0	+/-	0	30	+/-	70
Juvenile (15 - 100 cm tall)	26	+/-	31	17	+/-	13
DETRITUS						
Fallen dead trees	7	+/-	6	6	+/-	14
Standing dead trees	6	+/-	5	13	+/-	8
OTHER LIVE (at least 1m tall) TREE ATTRIBUTES						
Basal area (m2/ha)	24	+/-	5	24	+/-	3
Mean height (m)	6	+/-	1	5	+/-	0
Mean diameter (cm)	36	+/-	7	36	+/-	3
OTHER LIVE (at least 1m tall) TF	38%			70%		
JUNIPER RATIOS						
Live trees : 15 - 100 cm trees	7			12		
Live trees : fallen dead pieces	25			35		
Live trees : standing dead trees	28			16		
Live trees : dead trees or pieces	13			11		
Height : diameter	16			14		

(Badlands). Soil water characteristic curves are shown in Appendix 2 for the sites at which sampling was successful.

As discussed above, woody detritus is recognized as an important structural and functional component of old-growth forests. Two of the three aboveground sources of woody debris were measured. The unmeasured component, attached debris such as dead limbs and spires on live trees, appeared to be the most prevalent in these woodlands. One example of this was wood that had been dead for over 600 years on a 1600 year old tree found adjacent to a HRN plot.

A qualitative indication of the amount of dead debris attached to live trees may be provided by the form classes of the trees found at the site. Sixteen per cent of the live trees (height at least 1 m) in the study plots had canopies that were less than 50% complete, with many dead branches retained in the leafless portion of the canopy. Another 40% were missing 10 to 50% of the canopy and also had retained dead branches (see form analysis below). Standing and fallen dead trees occurred in the plots at all sites except the Green Mountain north interspace site. There was high variability within and between sites in the occurrence of both types of debris. Overall, the mean density of standing dead trees (13 ± 8 trees per hectare) was over twice the mean density of fallen detritus (6 ± 14 pieces per hectare). Standing dead trees also tended to be larger than the fallen pieces, which frequently included several pieces from a single tree. It appeared that the woodlands retained woody detritus primarily in standing live or dead trees, with only a minor component as large pieces on the ground.

Site comparisons

Each site in this study was distinct from the other six. The following descriptions highlight the differences. Comparative references (e.g. typical and average) refer only to the other sites within this study. Unless otherwise noted, the dominant understory species is *Festuca idahoensis* Elmer. Perennial forbs which had cover of 0.10% or greater are listed. No annual species had that level of cover at any site.

CONNLEY HILLS

The Connley Hills area had the highest elevations and steepest slopes, averaging 31% at the east site and 42% at the west site. The soil had a loamy sand texture and was rockier than at the other areas, with 39 and 64% rock at the surface. Canopies were reduced by at least half on 20% of the trees, the highest proportion of the three areas.

Connley Hills East had a large live tree population, with a strong detritus component and little regeneration; few shrubs; and relatively high species diversity. Tree cover and density were higher than the overall averages. Trees diameters were smaller than average. Evidence of regeneration was negligible. However, woody detritus was relatively abundant, due mainly to the amount of fallen debris.

Understory cover was lowest, at 6.8%. Shrubs were largely absent, with less than 0.5% cover and only 99 living shrubs per hectare. Dead shrubs outnumbered live shrubs, making up 68% of all shrubs. Perennial grass cover was 5%, with *F. idahoensis* (1.85%) and *Agropyron spicatum* (1.56%) codominant. Perennial forb cover was average, at 1%. The most common forbs were *Lupinus argentus* Pursh (0.5%), *Penstemon laetus* Gray (0.1%), and *Eriogonum strictum* Benth. (0.1%). Annual forbs were present, at 0.2% cover. Species richness was about average at 49 species present, while species diversity, which adjusts for the pattern of species dominance and rareness, was higher than at any other site. No species were good indicators only for this site.

Connley Hills West, with the higher heat loading of a steep west slope, had trees lower in density, cover, and height, with large basal diameters for their height. Tree density was significantly lower than on the east slope (114 versus 302 trees per hectare, Student's 2-sample t-test p-value<0.001). Trees were larger in diameter (p=0.001), but not significantly different in height (p=0.3) than on the east side. Multiple stems from near ground level were common. While not quantified, this site appeared to have a high amount of attached woody detritus. Many trees had dead spires, one or more of the multiple stems dead, or strip-bark supporting living tissue on a small portion of the tree. Relative to live trees, the numbers of standing dead trees and fallen pieces were higher at this site than at any other site. Tree morphology differences suggested that the west side stand was considerably older than the east side stand. Three of the plots supported 15 to

100 cm tall trees. Sufficient age information was not obtained to determine the extent to which these small trees had been suppressed or the rate of tree regeneration.

The perennial grass composition at this site was different than at the other sites. *Agropyron spicatum* (6.9%) was dominant, with *Koeleria macrantha* (Ledeb.) Schult. (0.9%) second in abundance. *F. idahoensis*, the most abundant grass among all sites, had less than 1/2% cover. Total perennial grass cover was 12%. Annual grasses and forbs cover were highest at this site, although still quite low (0.1 and 0.5%, respectively). Most common were *Astragalus filipes* Torr. (0.7%), *Eriogonum strictum* Benth. (0.3%), and *Crepis acuminata* Nutt. (0.1%). Species richness and diversity were lower than on the east slopes. This site had six good indicator species, more than any other site. These included four annual species, the dominant perennial grass *Agropyron spicatum*, and the perennial forb *Astragalus filipes*.

HORSE RIDGE AND BADLANDS

The Horse Ridge/Badlands area included one site, Horse Ridge North, on moderate north slopes (17%) and one site, Badlands, on lava mounds on otherwise nearly level terrain. This area was about 300 meters lower in elevation than the other areas. Tree, total herbaceous plant, and perennial grass cover were all low. Shrub cover, density, condition, and richness were high compared to the other sites. Compared to other areas, a high proportion of the trees with presettlement form at these sites had complete canopies. With a mean height of 4m, trees at these two sites and Connley Hills West were shorter than at the other sites.

Horse Ridge North had less surface rock (15% ground cover) more bare ground (46%), and more moss cover (10%) than average. Live tree density was average. Small trees and woody detritus were less common, with 21 live trees per juvenile-sized tree and 21 live trees per dead standing tree or downed piece. A live tree adjacent to one of the plots was found to be 1600 years old, the oldest *J. occidentalis* yet found.

Although total understory cover was average (11%), the 58 species present gave this site the highest species richness of all sites. Diversity was higher than at any site other than Connley Hills East. At 6% cover, the six shrub species present made up half of the understory cover. Only 14% of all shrubs were dead. Perennial grasses provided only 5% cover, with *F. idahoensis* (3.0%) dominant and *A. spicatum* subdominant (0.9%). The most common forbs were *Silene douglasii* Hook. (0.2%), *Erigeron filifolius* Nutt. (0.1%), and *Leptodactylon pungens* (Torr.) Nutt. (0.1%). Five species were good site indicators, including two species exclusive to the site, *S. douglasii*, and the shrub *Symphoricarpos oreophilus* Gray. The abundance and frequency of one other shrub and two annual forbs also distinguished this site. One of the forbs, *Gayophytum ramosissimum* Nutt. was found at all the other sites, but was less common at them.

The Badlands site had major microenvironmental differences with nearby Horse Ridge North. The lava mound topography restricted soil depths, so that trees appeared to depend on rock fractures for adequate rooting. Rock cover was above average at 37%, while only 18% of the ground was bare. The soil texture, sandy loam, was finer than at other sites. Juniper cover was low (11.4%), and not much greater than shrub cover (9.7%). More of the trees (85%) had the presettlement growth form than at any other site. With 9 live trees for every juvenile-sized tree, regeneration appeared to be occurring. Again, this conclusion could be misleading since the trees might be suppressed by a lack of resources and not small because of their youth. Fallen dead pieces were not abundant, but standing dead trees were more abundant than average. Dead trees may typically remain standing for very long periods, reducing the occurrence of large fallen pieces. The University of Arizona Laboratory of Tree-Ring Research sampled a tree at this site that had been standing dead for 500 years (unpublished data).

Shrubs were particularly abundant, averaging over 9000 living shrubs of five species per hectare and 10% cover. Perennial grass cover was low, at only 3%. *A. spicatum* cover (1.0%) slightly exceeded *F. idahoensis* cover (0.9%). Common forbs were *Leptodactylon pungens* (1.3%), *Eriogonum ovalifolium* Nutt. (0.1%), and *Senecio canus* Hook. (0.1%). Indicator species did not include any forbs. *Eriogonum microthecum* was unique to the Horse Ridge North and Badlands sites, however. It was present in 3 of the 9 plot cover transects at the Badlands. The subshrub *Leptodactylon pungens* had a very high indicator value. A native annual grass and the level of occurrence of *A. tridentata* also distinguished this site.

The interspaces between the Badlands mounds appeared to have much less available moisture. Pumice sands between two and four feet deep supported very few trees. Grass cover was less than 3% and was dominated by two species that were not found at any of the juniper sites, *Stipa occidentalis* and *Agropyron smithii*. Total plant cover was 17%, of which 12% was *A. tridentata* ssp. *vaseyana*.

GREEN MOUNTAIN

The three Green Mountain sites offered the greatest contrast in the apparent age of the woodlands. Aspects varied from north to south. However, slopes were generally under 5% so the effect of aspect was probably slight. All three sites were *J. occidentalis/A. tridentata/F. idahoensis* sites with average or above average perennial grass cover. The area is notable for its paucity of good indicator species.

The Green Mountain North-Mounds site occurred on rock mounds that occur irregularly within the North-Interspace site. Like the mounds at the Badlands, these mounds had limited soil depths and apparent dependence of the trees on rock fractures for rooting. Ground cover, which was more variable than at other sites, included 27% rock cover, 24% bare ground, and an unusually high 12% moss cover. Trees were high in density and average in size, resulting in high basal area. Fallen dead pieces were scarce but standing dead trees occurred at a typical ratio of one per 15 live trees. This site had the least evidence of regeneration of all sites, with 1 juvenile-sized tree per 34 other live trees.

This was the richest of the Green Mountain sites, with 53 species, and the most diverse. The 7.0% perennial grass cover included 5.3% *F. idahoensis* and 0.8% *Poa sandbergii*. The most common forbs were *Senecio canus* and *Lupinus argentus* (0.2% each) and *Erigeron linearis* (Hook.) Piper, *Penstemon laetus, Erigeron filifolius, and Eriogonum strictum* (0.1% each).

Moving off the mounds greatly reduced the old-growth "feel" of the area. The North-Interspace site was more open, with the lowest tree density sampled, 102 trees per hectare. Trees tended to be large, with a mean height of 6 m, and the largest mean diameter of all sites, 47 cm. Overall tree cover was about average as a result of the large tree size, but lower than at the other Green Mountain sites. Juniper litter cover was only 13%, compared to 23% at the other Green Mountain sites. The postsettlement growth form occurred in one third of the trees. No dead trees or large downed pieces occurred in the plots. Regeneration evidence was very strong, with one juvenile-sized tree per 2.2 other live trees. At 74%, this site had the lowest percentage of trees (over 1 m tall) meeting the old-growth criteria (see Table 14 and discussion thereof) of all sites.

The interspaces had the highest bare ground (63%) and the lowest rock cover (2%) of all sites. Understory cover was average for each functional type. Species richness was typical of the other woodlands, but diversity was lower than at any site other than Green Mountain South. *Festuca idahoensis* (7%) dominated the perennial grass component (8%). The most common forbs were *Erigeron filifolius*, *Lupinus argentus*, and *Antennaria dimorpha* (Nutt.) T. & G. (0.2% each). The understory may have been affected to some extent by cattle, which were present for part of the field season at this site and possibly at Green Mountain South.

The woodland also appeared to be younger at the Green Mountain South site. At 38%, this site had far fewer trees in the presettlement form than any other site. The next lowest was the north interspaces at 65%. The south site had a low proportion of standing dead trees and above average proportions of fallen pieces and juvenile-sized trees, with 1 per 28, 25, and 7 other live trees respectively.

Conditions did not favor shrubs, judging by their low cover (1%) and the high proportion of dead shrubs (41%). Herbaceous plant cover was high (14%) due to the strongest perennial grass component (12%) of any site. *F. idahoensis* was strongly dominant, with 10% cover. Both species richness and diversity were lowest at this site. *Antennaria dimorpha* (0.4%), *Lupinus argentus* (0.4%), and *Senecio canus* (0.2%) were the most common forbs. This site also had very low surface rock (3% cover) but a high proportion of bare ground (49%).

Understory relationships

Relationships between plant composition and site environmental conditions were investigated. Variations in plant attributes, by functional type, were compared to the abiotic environmental variables % sand in soil, % clay in soil, rock cover, bare ground cover, heat load (aspect), slope, and elevation (Table 8). While each abiotic variable had significant correlation with some functional type attribute, sand, rock cover, elevation, and heat load were most commonly correlated. Shrub cover was very strongly positively correlated ($r^2 = 0.66$) with the combination of elevation, ground cover by rock, and clay content of the soil. Perennial grass cover increased with increases in elevation and the sand-sized soil fraction ($r^2 = 0.46$). Understory cover, which was dominated by perennial grass, showed a weaker correlation with the same parameters ($r^2 = 0.20$). Species richness was negatively correlated with heat load, and positively correlated with sand content of the soil, heat load, slope, and rock cover ($r^2 = 0.36$). Other significant findings included correlation of juniper cover with elevation, sand, and heat load ($r^2 = 0.38$). Tree cover was found to increase by almost 1% for each 1% increase in sand content of the soil and by almost 8% for each 100m increase in elevation, while heat loading had a smaller effect (decrease of 1% cover for each 0.1 increase in heat load).

The next step in this analysis looked at the effect on the understory of all other site conditions, both tree parameters and the abiotic attributes. Tree parameters included tree density, cover, basal area, canopy area, and litter. The tree parameters only had a significant effect on perennial grass cover and understory richness, as shown in Table 9. Perennial grass cover was strongly correlated ($r^2 = 0.55$) with tree density, sand content of soils, and elevation. Increasing juniper density by 100 trees/hectare was associated with a 1% decline in perennial grass cover. A 50 tree/hectare increase in juniper density was associated with a unit decrease in understory species richness.

Table 9 also shows the significant results of comparisons between cover of each understory functional type and other cover variables: the other functional types, juniper cover, and the other categories of ground cover including juniper litter, moss, bare

Table 8 Plant community correlations with environmental attributes. Variables showing a significant ($p<0.05$) result in stepwise regression are shown, along with the composite correlation coefficient. P-values are from ANOVA Type III (Wald) analysis.

Functional Type	Attribute	R^2	Variable	*B*	p-value
Perennial grass	cover	0.46	% sand	+0.53	0.0001
			elevation (m)	+0.04	0.0001
Shrub	cover	0.66	elevation (m)	-0.022	0.0001
			% rock cover	+0.070	0.0005
			% clay	+0.62	0.028
Annual grass	cover	0.21	heat load	+0.57	0.0013
			slope (°)	+0.00094	0.042
Annual forb	cover	0.40	slope	+0.23	0.0001
			heat load	+0.0071	0.0046
Understory	cover	0.20	% sand	+0.053	0.0035
			elevation	+0.016	0.0332
Understory	richness	0.36	% sand	+0.35	0.010
			heat load	-7.7	0.015
			slope	+0.28	0.021
			% rock cover	-0.086	0.033
Tree	density	0.35	bare ground	-4.6	0.0010
			heat load	-160	0.0012
			% rock cover	-2.8	0.0375
Tree	density	0.21	heat load	-182	0.0012
(bare ground excluded from analysis)			% rock cover	+1.3	0.0375
Tree	cover	0.38	elevation	+0.079	0.0001
			heat load	-11	0.0047
			% sand	+0.96	0.020

Table 9 Functional type correlations with other site conditions. Variables showing a significant ($p<0.05$) result in stepwise regression are shown, along with the composite correlation coefficient. P-values are from ANOVA Type III (Wald) analysis.

Functional Type	Attribute	R^2	Variable	*B*	p-value
Correlations with tree and abiotic parameters					
Perennial grass	cover	0.55	% sand	+0.49	0.0001
			elevation (m)	+0.034	0.0001
			tree density (/HA)	-0.0098	0.0012
Understory	richness	0.30	tree density	+0.020	0.0006
			juniper litter cover	-0.19	0.026
			heat load	-4.4	0.037
Correlations with cover of other functional types, juniper litter, and other ground covers					
Shrub	cover	0.38	juniper cover	-0.10	0.010
			perennial grass	-0.46	0.0001
			annual forb	-4.7	0.0238
Perennial grass	cover	0.37	shrub	-0.38	0.0001
			moss	-0.23	0.0087
			annual forb	-3.4	0.043
Perennial forb	cover	0.09	crust	-0.20	0.018
Annual grass	cover	0.31	annual forb	+0.14	0.0001
Annual forb	cover	0.46	annual grass	+2.2	0.0001
			juniper litter	-0.0049	0.031
			perennial forb	-0.028	0.037

ground, rock, and cryptogamic crust. Other litter was excluded from the analysis, since it would be expected to be dependent on the amount of understory cover. Shrub cover varied inversely with juniper cover, perennial grass, and annual forb cover ($r^2 = 0.38$). However, an increase in juniper cover of 10% (for example from 20 to 30%) was associated with only a 1% change in shrub cover. Perennial grass cover was negatively related ($r^2 = 0.37$) to shrub cover, moss cover, and annual forb cover. A 10% increase in moss cover corresponded to a 2% decrease in perennial grass. The regression coefficients for annual forbs shown in Table 9 are relatively large. Given the low range and magnitude of annual forb cover measured however, the importance of annual forbs in these relationships was also low.

Tree age and form analysis

A total of 1132 trees over 1m tall occurred within the plots. Sixty-nine (69) per cent of these trees had the presettlement form. In addition to the attributes listed in Table 5, large lower limbs, dead spikes, and strip bark supporting a limited canopy were common. Cavities occurred in the boles less frequently. At Connley Hills West, in particular, many of the trees with a presettlement appearance had multiple trunks. The lichen *Letharia columbiana* was frequently found on dead limbs of live trees.

The form distributions were analyzed for each site (Figure 3). Postsettlement trees predominantly had full canopies, with 80% in form class 1 (canopy more than 90% complete), 19% in form class 2 (50% to 90% canopy), and the remaining 1% in form class 3 (10 to <50% canopy). Green Mountain had the highest proportion of postsettlement trees (37%), with 25%, 35%, and 62% of trees having postsettlement form at the North-Mounds, North-Interspaces, and South sites, respectively.

Among presettlement trees, the second form class was most common with 48% of the trees, followed by form class 1 with 31%. Twenty (20) per cent of the presettlement trees had less than half of a full canopy (15% in form class 3 and 5% in form class 4, i.e. less than 10% canopy). Similar distributions were found in each area, although the Horse

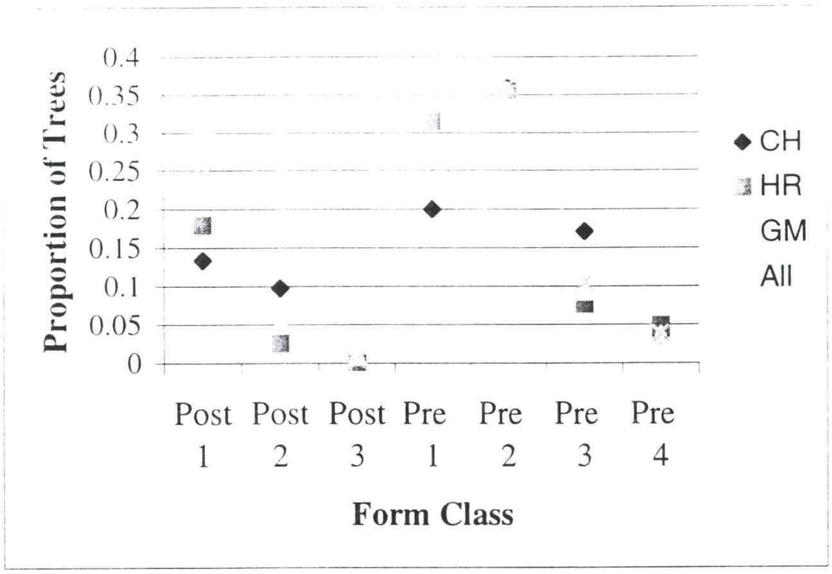


Figure 3 Tree form distribution by area and overall. Area values are based on an average of all plots in the area.

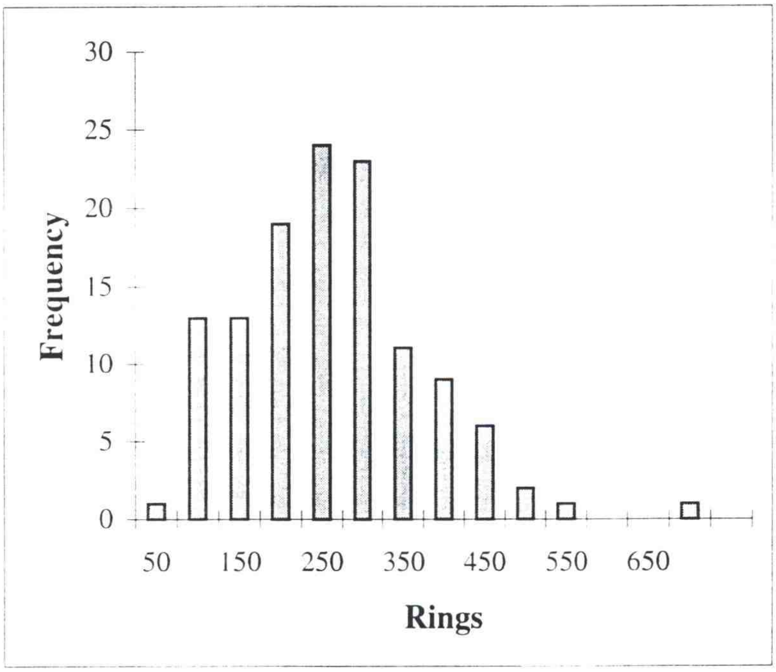


Figure 4 Age distribution of trees sampled in plots. Ages are based on incomplete core samples for most of the trees, so are underestimated. Maximum ring count is 666.

Ridge area had a higher proportion of trees with full canopies and the Connley Hills area had a higher proportion with less than 50% canopies. The poorer canopy condition of pre- and postsettlement trees at Connley Hills suggested that the tree form was affected by the harshness of the growing conditions at this area, including steep slopes and stony soil surfaces.

The trees for which complete or nearly complete cores were obtained had a median ring count of 288 years. This is a highly conservative estimate of the average tree age, since rings were missing, this species rarely produces false rings, and the sample was biased toward younger trees by the difficulty of obtaining complete cores in older trees. Seventy-eight (78) per cent of the trees had more than 150 rings, indicating they were presettlement trees. Figure 4 shows the distribution of ring counts for these 123 trees. The onset of heartwood rot around the 1740s caused the apparent peak in ages around 274 years. Full cores were not obtained at all sites. The 123 trees include 42 from Green Mountain South, 25 from Horse Ridge North, 22 from Connley Hills West, 10 from Green Mountain North-Mounds, and 4 from Green Mountain North-Interspaces.

Outward physical attributes did not appear to be reliable predictors of tree age. Height, diameter, basal area, canopy area, and tree form were correlated with age for the 26 trees with complete core samples. No single attribute was significantly correlated ($p \leq 0.05$) with tree age. The combination of height, diameter, and basal area (or diameter squared) was significantly related to age ($p=0.0008$), but explained only 49% of the variation. Diameter and basal area alone explained 36% of the variation ($p=0.0035$).

With one exception, all trees in postsettlement form class 2 and higher were over 200 years old and 16 cm in diameter (Table 10). In postsettlement form class 1, 62% of the trees are under 200 years old. All trees with 200 or more rings had diameters greater than 15 cm, while younger trees had diameters of 21 cm or less. For the tree population as a whole it can be conservatively assumed that trees were over 200 years old if they were in form class 2 or higher and had diameters of at least 15 cm, although this relationship lacks statistical rigor. Applying this age/form relationship to the 28 aged trees results in one tree being misclassified as over 200 years old and five trees being misclassified as under 200 years old.

Table 10 Characteristics of aged trees within plots. Trees that were older than predicted by the proposed age/form relationship are indicated by bold type, while trees that were younger than predicted by the proposed age/form relationship are underlined.

Form Class	Rings	Diameter (cm)	Form Class	Rings	Diameter (cm)
Post 1	73	10	Post 2	245	17
Post 1	129	10	Post 2	263	30
Post 1	134	20	<u>Pre 1</u>	<u>121</u>	<u>15</u>
Post 1	140	11	Pre 1	214	40
Post 1	141	11	Pre 1	296	44
Post 1	157	21	Pre 1	300	17
Post 1	164	15	Pre 1	327	23
Post 1	165	20	Pre 1	331	36
Post 1	**235**	**22**	Pre 2	274	68
Post 1	**236**	**52**	Pre 2	326	52
Post 1	**240**	**30**	Pre 2	712	33
Post 1	**272**	**31**	Pre 3	270	19
Post 1	**291**	**26**	Pre 3	318	28

Multivariate analysis

Generally, the same pattern was repeated by each of the multivariate techniques, although each technique provides different insights. Plots grouped strongly by area. The Horse Ridge/Badlands area broke out further along site lines, while the sites within the other two areas intersperse. The Multi-Response Permutation Procedure (MRPP) results provided some quantitative evidence of the difference between sites. The two sites at Connley Hills were slightly different. The Green Mountain North and South sites have larger differences, and the two Horse Ridge sites have the greatest differences.

Figure 5 shows the hierarchical agglomerative clustering results for the 63 plots. At 25% of the original information remaining, the plots clustered into three groups which, with only four exceptions, match the three areas in which sites were located. At higher levels of information remaining, the two sites in the Horse Ridge area separated out. For the other areas, the sites within an area do not appear to cluster together. This suggests that there is a stronger influence of area than site on community composition for most of the sites and that differences between areas overwhelm the differences within areas.

The MRPP results indicated significant differences between areas and between at least two of the seven sites in species space, as shown in Table 11. The chance-corrected within-group agreement, R, is 0.12 between areas and 0.18 between sites (on a scale of -1 to +1), indicating that there is some difference and that, as should be expected, the difference is greater at the site level than at the aggregated area level.

Results for preplanned comparisons of sites within areas are also shown in Table 11. The difference between the east and west face sites on Connley Hills was statistically significant ($p = 0.003$) but small in magnitude. For the sites at Horse Ridge, the difference was significant ($p = 0.00002$) and larger in magnitude. At Green Mountain, there was a fairly small but significant ($p = 0.0003$) difference between the south site and the interspace site on the north side. The difference between the mounds and interspaces on the north side was not significant ($p = 0.08$).

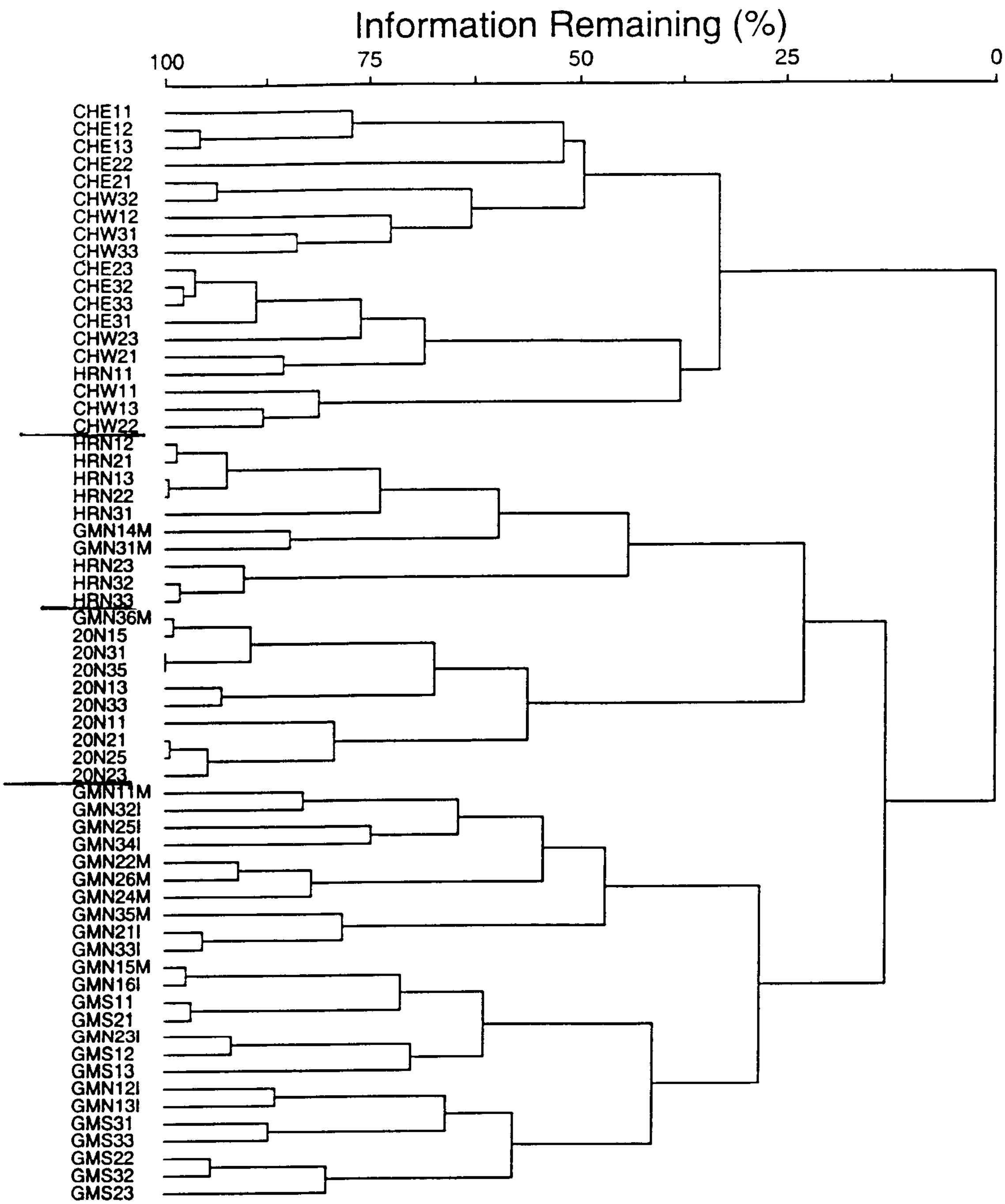


Figure 5 Results of hierarchical agglomerative cluster analysis of 63 study plots. The site codes are ass follows: CHE## = Connley Hills East, CHW## = Connley Hills West, HRN## = Horse Ridge North, 20N## = Badlands, GMN##M = Green Mountain North - mounds, GMN##I = Green Mountain North - interspaces, and GMS## = Green Mountain South. The numbers identify the transect and individual plots at a site.

Table 11 Multi-Response Permutation Procedure results for selected comparisons.

Comparison	T-statistic	P-value	R
3 areas	-29.3	<0.00001	0.122
7 sites	-23.6	<0.00001	0.177
Connley Hills sites	- 3.8	0.003	0.039
Horse Ridge sites	- 7.6	0.00002	0.094
Green Mountain sites	- 6.3	0.00001	0.056
Green Mtn. North-Interspaces and South	- 5.4	0.0003	0.055
Green Mountain North sites	- 1.5	0.08	0.013

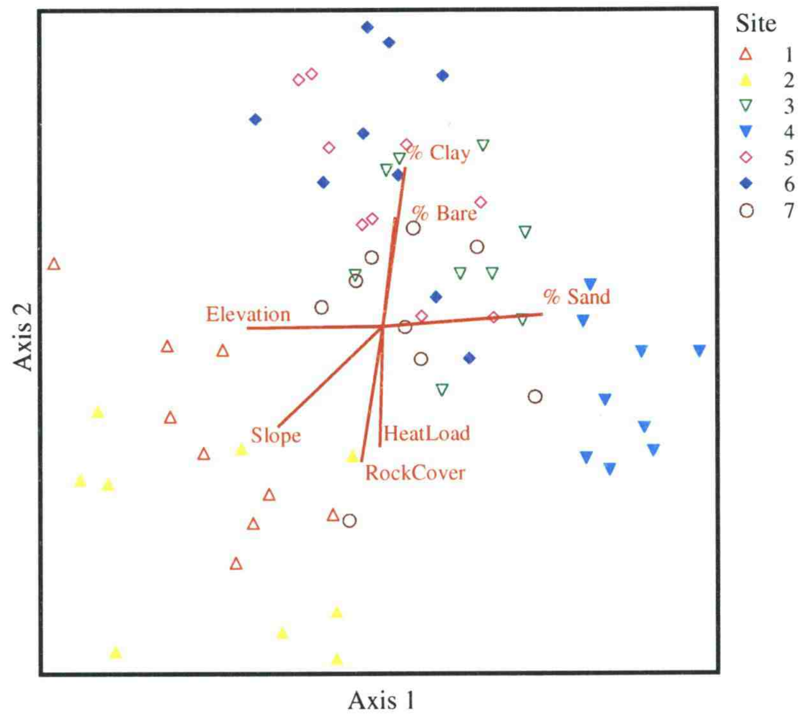
Table 12 Species with indicator values of 40 or greater. High values are in boldface. Type indicates the species functional type (af for annual forb, ag for annual grass, pf for perennial forb, pg for perennial grass, and s for shrub). Species names are given in Appendix 1.

Species	Type	CHE	CHW	HRN	BAD	GMNM	GMNI	GMS
AGSP	pg	13	**59**	8	8	4	1	6
ARTRV	s	0	2	19	**41**	17	15	3
ASFI	pf	8	**58**	0	0	0	0	0
BRTE	ag	11	**42**	0	1	2	1	3
CHVI	s	0	1	**44**	13	1	2	0
COGR	af	4	0	**44**	0	0	0	0
COPA	af	6	25	5	0	**51**	8	0
DEPI	af	0	**69**	0	9	0	0	0
ERVI	af	21	**59**	0	0	0	0	0
GARA	af	0	0	**44**	0	0	0	0
LEPU	pf	0	0	5	**85**	1	0	0
LISE	af	0	0	12	0	2	0	**45**
MEAL	af	**28**	**40**	0	0	0	0	1
MIGR	af	2	2	0	0	11	**58**	5
PHLI	af	0	**57**	8	0	0	0	0
SIDO	pf	0	0	**44**	0	0	0	0
SYOR	s	0	0	**67**	0	0	0	0
VUMI	ag	0	0	0	**44**	0	0	0

Indicator Species Analysis was used to identify the species that best differentiated between sites. Table 12 shows the indicator values for species which had a value greater than or equal to 40 (an arbitrary level of significance). The Monte Carlo test gave significant results for the observed maximum indicator value for each species listed (p-values < 0.05). Overall, most of the strong indicator species were shrubs and annual species. Both these functional types are listed here in higher proportions than they occur in the list of all species.

The three-dimensional NMS ordination also showed the plots from the three areas occupying different sectors of ordination space, as shown in Figure 6. The axis numbers were assigned arbitrarily in this figure, since NMS does not arrange axes in order of importance. This ordination had significant results (Monte Carlo p-value = 0.05, correlation coefficient for ordination distance and distance in the original 56-dimensional space = 0.83). Generally, each of the three areas occupied a different sector of species space and, within an area, the sites were distinct. The exception is the Green Mountain area, where the two north sites intermingle and Green Mountain South overlaps with the North-Interspaces. Some plots from this area extended into sectors occupied by other areas. The arrangement in ordination space illustrates the MRPP results for the Green Mountain sites, with the two north sites intermingled with each other with little overlap of the south site.

Correlations between understory composition and other plot attributes can be seen in the vectors overlaid on the ordination. The ordination axes were correlated with site topography, ground covers other than vascular plants, species richness, total understory cover, and the tree parameters density, mean height, mean diameter, basal area, and canopy area. Figure 6 shows overlays of vectors for the variables that had correlation coefficients of 0.30 or greater with any axis. The strongest correlation between community composition and the abiotic parameters were, in declining order, % sand in soil (correlation with Axis 1=0.70), elevation (0.59 with Axis 1), % clay in soil (0.53 with Axis 2), slope (correlation with Axis 1 = 0.46), rock cover (0.45 with Axis 2), and heat load (0.40 with Axis 2). The high correlation of bare ground with community composition (0.36 with Axis 2) likely reflects a combination of cause and effect.



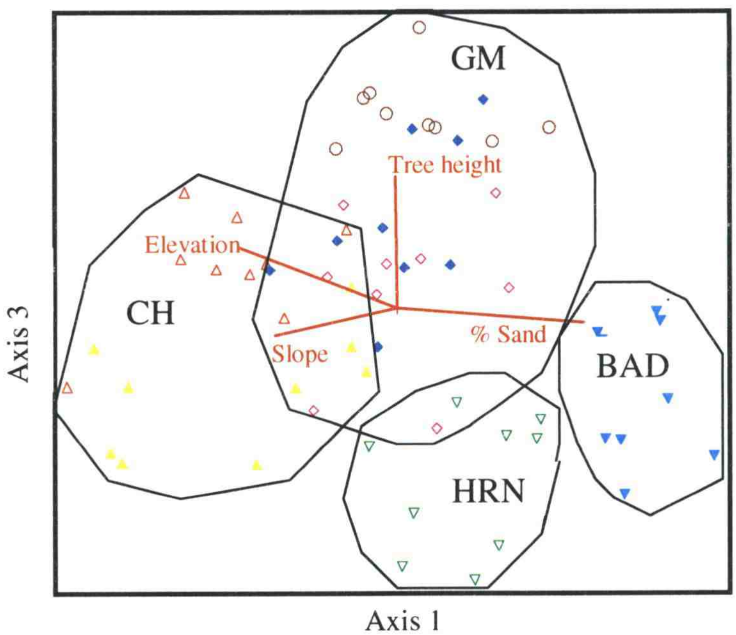


Figure 6 Arrangement of plots in 3-dimensional ordination space, with overlays of site attributes having correlations of 0.30 or greater with any axis. Vectors are scaled in proportion to the correlation coefficient. For example, the correlation between elevation and Axis 1 is 0.594 in the negative direction. Loops surround plots by area. Site key is as follows: 1 CHE, 2 CHW, 3 HRN, 4 BAD, 5 GMNM, 6 GMNI, 7 GMS.

Most tree parameters correlated poorly (correlation coefficient less than 0.10) with understory composition. The exception was tree height (0.48 with Axis 3). This suggests that tree height was responsive to the same environmental factors that affect understory composition. Perhaps most significantly, tree density showed no correlation (<0.03 with each axis) with understory composition. In an additional analysis, strong correlations were not seen between the ordination axes and total cover by functional group. Perennial grass (0.26 with Axis 2 and 0.20 with Axis 3), and annual forbs (0.26 with Axis 1) had the highest correlations.

Numerous individual species responded to the same gradients as the overall communities in the NMS ordination, as shown in Figure 7. Some of the same species were shown to be indicator species for the sites. The two dominant grasses responded along the clay content gradient, with *F. idahoensis* showing a strong positive correlation (0.44 with Axis 2) and *A. spicatum* showing a similarly strong, but negative, correlation (0.48). Other species responding to soil clay content were *Carex rossii* Boott, *Stipa thurberiana* Piper, *Bromus tectorum* L., and *Eriogonum vimineum* Dougl. *Leptodactylon pungens* correlated with the sand content gradient. *Koeleria macrantha* and *Eriogonum strictum* correlated positively with elevation and negatively with sand content.

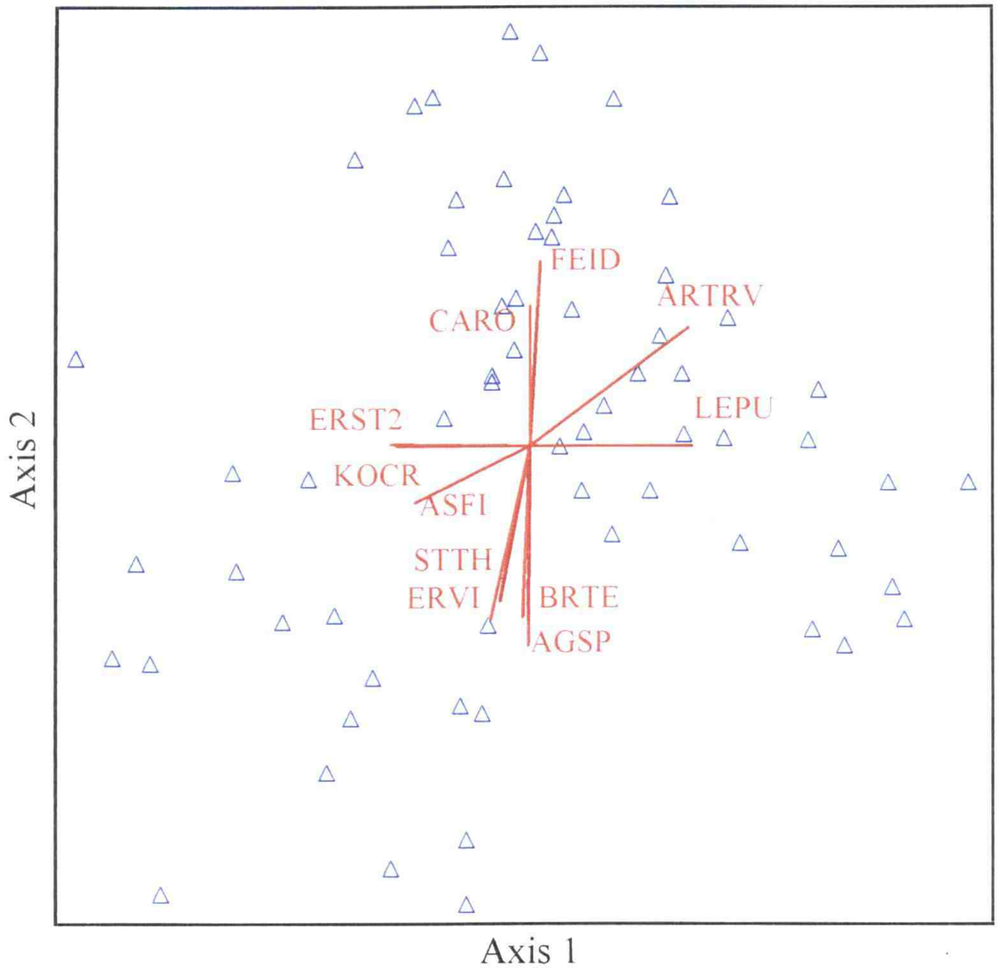


Figure 7 Overlay of species with highest correlations with ordination axis. Species shown have a correlation coefficient of 0.30 or greater. Vectors are sized in proportion to the correlation coefficient, with AGSP and Axis 2 having a correlation coefficient of 0.479. Axis 3 correlated this strongly only with LUAR and ANDI (both positive correlations).

DISCUSSION

Characteristics of an old-growth juniper woodland

Woodgate et al. (1996) presented a useful approach to a working definition of old-growth forest based on forest growth stage, ecological vegetation class, and disturbance history. Crown morphology was used to classify trees into regeneration, regrowth, mature, or senescing growth stages. Disturbance levels were undisturbed, negligible/natural disturbance, negligible/unnatural disturbance, significant/natural disturbance, and significant/unnatural disturbance. Increasing disturbance corresponded to a decrease in intangible old-growth significance but was not considered to affect structural old-growth significance. On a schematic of growth stage versus disturbance, old-growth encompassed the region from senescing without disturbance out to an arbitrary stopping point in the mature with negligible disturbance region.

Using this approach, the sites included in this study fall solidly in the old-growth domain. With the exception of the interspace portion of Green Mountain North, all plots contained a high proportion of senescing trees as evidenced by partial canopies, dead spikes, and lack of leader growth. Evidence of natural disturbance such as fire, insect infestation, or windstorm was absent or negligible. Anthropological disturbances included a small amount of woodcutting in the Badlands and cattle grazing at Green Mountain. These disturbances did not appear to have impacted the structure of the sites. The sites reveal some of the range of structural characteristics of old-growth *J. occidentalis/A. tridentata/F. idahoensis*, *J. occidentalis/A. tridentata/F. idahoensis-A. spicatum*, and *J. occidentalis/A. tridentata/A. spicatum* communities in aeolian sand-derived soils.

These results provide the basis for the development of a quantitative old-growth western juniper description (Table 13), even though structural characteristics vary considerably across local and regional scales. Essential characteristics of old-growth status are a minimum density of 80 old-growth trees/hectare, with old-growth trees

Table 13 Old-growth western juniper attributes based on seven study sites.

Parameter	Amount
Live trees - essential conditions	
Old tree density	80 trees/ha minimum
Old tree identifiers	Diameter of at least 16cm, less than 90% of full canopy (used to identify trees at least 200 years old)
Decadence present	Yes, as dead spires, one or more of multiple boles dead, large branches dead, or deformed tops
Growth rates	Trees are slow growing, based on lateral and terminal leader growth
Number of tree canopies	Single story
Total canopy cover	10-35%
Standing dead trees - essential conditions	
Density	10 dead trees/ha minimum
Diameter at 30cm	25cm
Down dead pieces - essential conditions	
Density	1 piece/ha minimum
Minimum size	3m length, 25cm diameter at large end
Live trees - common conditions	
Basal area	$10m^2$/ha minimum
Growth forms	1/2 to 3/4 of trees have presettlement growth form. Many trees under 3m appear suppressed, particularly when under or near an older tree's canopy.
Other common attributes	Variation in tree ages and diameters. Evidence of fire and other disturbances limited within a stand, and not obviously affecting tree distribution
Understory - common conditions	
Understory cover	< 20%
Herbaceous plant cover	< 15%
Perennial grass cover	≤ 12%
Shrub cover	≤ 10%, may be <1%
Plant distribution	Highest herbaceous plant density is near the edge of or under tree canopies. Annuals may be most common under canopies. Shrubs occur throughout the interspaces.
Bare ground	The % of bare ground cover is highly variable and related to rock cover and topography. Some pedestaling and local soil movement may occur, but soil movement off site should not be evident.

considered to be trees with a diameter of at least 16 cm and with less than 90% of a full canopy. The oldest trees are slow growing, based on lateral and terminal leader growth. Tree diameters vary. Canopy cover ranges between 10 and 35% in the woodland. Dead wood is present primarily as retained detritus in live trees and as standing dead trees. A minimum of 10 standing dead trees/ha and 1 large (3m length, 25cm diameter) downed piece/ha would occur.

Other attributes of old-growth may include a predominance of the presettlement growth form. Between ½ and 3/4 of the trees would generally have the old-growth form. Trees would not be even-aged. Most small trees (under 3m) would be low in vigor, as evidenced by repressed growth, small canopy areas, spindly appearances, and little or no leader growth. Tree basal area would be at least 10 m^2/ha. Evidence of fire within a patch would be minimal, limited to individual trees, although a large old-growth woodland could have a matrix of woodland patches and open, fire-scarred patches.

The Green Mountain North-Interspace woodland appears to be the youngest of the seven sites and has not yet fully developed some of the old-growth characteristics. The interspace plots lacked woody detritus in the form of large downed pieces and standing dead trees, which conflicts with the characteristic quality of accumulations of large dead woody material in old-growth forests (USDA Forest Service 1993). However, some of the live trees contained large woody debris. The interspaces had an average of only 74 old-growth trees/ha. This low density of old-growth trees may not be significant since some subjectivity is necessary to setting minimum tree density criteria. By itself, this site might be considered to be at the beginning of the old-growth stage. The site, however, must be considered in a landscape context. The interspaces are one element of a matrix which includes the rocky mounds, and those mounds clearly support old-growth communities. While no measure of relative areas was obtained, the combined site clearly supports an old-growth woodland.

Old-growth juniper woodlands in other locations may have different structural characteristics. A full working definition of old-growth western juniper woodlands needs to consider the range of soils where old-growth juniper occurs, plant communities with different understory dominants, and the acceptable limits of natural and anthropogenic disturbance.

Woody detritus in the old-growth woodland

Woody detritus appears to function differently in these woodlands than in more mesic old-growth systems. Dead wood is predominantly retained aloft throughout much or all of the decay process, as evidenced by tree boles that have been dead for up to 500 years and dead wood retained on live trees for up to 600 years. In combination with the long life span of the trees, this suggests extremely long nutrient cycling periods. In comparison, the estimated time for 95% decay of fallen trees in the Pacific Northwest is 273 years for western hemlock or Sitka spruce and 429 years for Douglas-fir (Maser et al. 1998).

J. occidentalis debris appears to deteriorate more through abiotic weathering than through biotic decomposition. This has a significant, and restrictive, impact on the functions of woody detritus in the old-growth community. The detritus appears to provide limited habitat value, such as in cavities in standing dead trees. Fungal activity appears to be limited. Large fungi were observed on the surface of the wood, but networks of fungal hyphae were not observed in wood in any stage of decay. Arthropods such as carpenter ants also were not observed in the woody debris. Nitrogen fixation that occurs in moist, well-decayed woody debris in more mesic systems (Franklin et al. 1981) likely was absent or reduced.

Categorizations have been developed as a starting point for *J. occidentalis* woody detritus classification (Tables 14 and 15). These classifications are observational, from the limited amount of field work described above. The schemes are patterned on the five stage schemes used for species in more mesic systems. In applying the schemes, a piece of woody detritus should be placed in the category it most closely resembles. Individual pieces may not match all characteristics of these profiles of typical pieces.

Table 14 Classification of standing western juniper debris. Partially live trees, in Class I, are included because of the high proportion of dead wood retained on partially live trees in old-growth junipers. Class I trees could be given a second rating indicating the condition of the dead portion of the tree. For example, Class I(IV) would indicate a partially live tree on which the dead portion alone would rate as Class IV.

ATTRIBUTE	CLASS DESCRIPTION				
	CLASS I	CLASS II	CLASS III	CLASS IV	CLASS V
Tree status	Partially live. Live may be on separate trunk or supported by strip-bark.	Dead	Dead	Dead	Dead
Branch system	Intact on live part, variable on dead.	Fine branches present.	2/3 of large branches intact. Fine branches absent.	2/3 of large branches reduced in length by at least half.	90% of large branches reduced by 75%.
Bark	Yes, on some or all of bole.	Generally some bark.	Generally some bark.	May be strip bark present.	Absent.
Height	Full on live part, may be reduced on dead spike.	Full or slight reduction of spike.	Generally full or slight reduction of spike.	Spike generally reduced.	May be reduced to stump.
Other	*Letharia* sp. often present on dead wood.				Tree reduced to spike form or stump.

Table 15 Observational chronosequence of fallen woody detritus.

ATTRIBUTE	CLASS DESCRIPTION				
	CLASS I	CLASS II	CLASS III	CLASS IV	CLASS V
Bark	Present on at least 1/3 of bole.	On less than 1/3 of bole.	Little or none.	Little or none.	Absent.
Branch system	Fine branches present.	2/3 of large branches intact. Fine branches absent.	2/3 of large branches reduced in length by 75%.	Underside branches absent. 90% of top-side branches reduced by 75%.	None or few stubs on top side of bole.
Bole position	Held off ground by branches.	Off ground.	Off ground.	Off ground.	On ground.
Structural integrity	Solid, cambium intact.	Solid, cambium intact.	Solid, cambium intact.	Solid, ridges evident on top-side of cambium.	Wood peeling in layers. Bole may still be solid.

Comparison of old-growth and transitional communities of J. occidentalis

Old-growth woodlands differ from younger mature stages of community development. Driscoll (1964a and 1964b) reported on two "mature" juniper woodlands in central Oregon: a *J. occidentalis/A. tridentata/A. spicatum* association at The Island and a *J. occidentalis/A. tridentata/F. idahoensis -Lupinus* association. The trees at The Island were reported to be mature and even-aged, with no age information presented, but with distribution controlled by fire disturbance. The *J. occidentalis/A. tridentata/F. idahoensis -Lupinus* community was reported to be in excellent, climax condition on Entisol soils containing 30% pumice sands. Charred trunks and roots suggested that tree distribution had also been affected by fire disturbance in this area.

The two communities analyzed by Driscoll had lower juniper cover, higher shrub cover, and higher perennial herbaceous cover than the old-growth communities in this study (Table 16). At The Island, species richness was lower while annual cover was higher. Resistance to invasion by alien species was lower, as evidenced by *Bromus tectorum* cover of almost 2% despite minimal anthropogenic disturbance. Bare ground plus litter was relatively high on The Island..

It would appear that the woodlands studied by Driscoll were in transitional stages toward fully-developed mature woodlands. The stability and relative richness of an old-growth community were lacking. Shrubs in juniper woodlands begin to thin in the early stages of stand closure (Miller et al. 1997). Lower juniper cover and higher shrub cover suggest that this reduction had not been completed. The shrub and fire evidence place these woodlands in late-mid to early-late stages of woodland development. These comparisons highlight the importance of distinguishing the growth stage of juniper woodlands, particularly when referencing studies that did not present age data.

Table 16 Comparison of old-growth *J. occidentalis* communities to earlier seral communities in central Oregon described by Driscoll (1964a, 1964b).

Parameter	JUOC/ARTR/ AGSP	JUOC/ARTR/ FEID	Old-growth sites average (range)
Juniper cover	10%	12%	23% (11-33%)
Shrub cover	10%	7%	3% (0-10%)
Shrub species	2	≥ 3	4 (1-6)
Perennial grass cover	13%	13%	7% (3-12%)
Perennial forb cover	1%	4%	1% (1-2%)
Annuals cover	2.4%	0.1%	0.2% (0.0-0.6%)
Species richness (total species noted)	32	not noted	47 (40-58)
Bare ground	42%	not noted	32% (5-63%)
Litter cover	31%	not noted	25% (17-29%)

Comparison of J. occidentalis and other old-growth communities

These results compare favorably, but with important differences, to the pinion-juniper old-growth definitions developed by the USFS (Mehl 1992, Popp et al. 1992). Individual sites were compared to the pinion-juniper (P-J) old-growth definition using the age approximation developed above (Table 17). Tree density at each site meets or exceeds the P-J definition. The lowest density was found in the interspaces of Green Mountain North, followed by Green Mountain South. Canopy cover was less than in the P-J, reflecting the open nature of the *J. occidentalis* woodlands. Trees obtained old-growth age at a much smaller diameter than in the P-J. However, minimum tree basal areas in the plots were substantially higher than the 5.3 m^2/ha in the P-J, ranging from 6 m^2 of old growth basal area/ha in the Green Mountain North-Interspace site to 23 m^2/ha in the adjacent mounds. Other live tree parameters were consistent with the P-J definition. The distribution of woody detritus was reversed. Because *J. occidentalis* woodlands retain more woody detritus as standing trees than as fallen debris, the density of standing dead trees was much higher at six of the sites than in the P-J. Downed woody debris was less common in five of the seven sites than in the P-J and never exceeded the frequency of standing dead trees, as it did in the P-J.

Comparison of old-growth western juniper and ponderosa pine (*Pinus ponderosa Dougl.)* provides a sense of how old-growth character can change more locally. *P. ponderosa* occurs in central Oregon in areas with similar elevations and slightly greater precipitation, often overlapping in range with *J. occidentalis*. The Forest Service prepared a definition of *P. ponderosa* old-growth (Table 18) for Oregon and the other USFS. Region 6 states. There are wide differences in expected stand characteristics. The juniper woodlands contain a higher density of the largest size of juniper trees, but these trees are much smaller than the old-growth pines. Similar densities of standing dead trees would be expected. However, the ratio of old-growth trees to standing dead trees is higher in the *J. occidentalis* woodland (8.0 versus 3.3). Fallen dead trees are more plentiful in the pine forest. Typical understory cover in the pine forest is much greater than that found in the juniper woodlands.

Table 17 Comparison of *Juniperus occidentalis* sites to the pinion-juniper old-growth criteria.

Parameter	P-J	CHE	CHW	HRN	Bad	GMNm	GMNi	GMS
LIVE TREES								
Old-growth trees per HA and (SD) (1)	74	270 (92)	90 (33)	198 (83)	171 (59)	255 (96)	74 (36)	82 (26)
Minimum diameter (cm)	30	16	16	16	16	16	16	16
Mean age of old-growth trees and [sample size]	200	no data	341 [14]	325 [17]	242 [14]	222 [8]	272 [3]	276 [17]
Decadence present	yes	yes	yes	yes	yes	yes	yes	yes
Number of canopies	1	1	1	1	1	1	1	1
Upper trees slow growing (2)	yes	yes	yes	yes	yes	yes	yes	yes
Variation in tree diameters	yes	yes	yes	yes	yes	yes	yes	yes
Minimum tree basal area (m2/HA)	5.3	13	10	19	10	34	24	17
Canopy cover	35%	33%	14%	18%	11%	32%	21%	31%
% of trees meeting old-growth definition	not used	73	77	62	67	72	73	46
STANDING DEAD TREES								
Trees/HA > than 25 cm in diameter	2.5	37	27	14	34	35	0	14
DOWN WOOD								
Pieces/HA ≥ 3 m long and 25 cm in diameter	5	16	5	3	3	1	0	4

NOTES

(1) Trees of indicated diameter. JUOC trees are in form class 2 or higher.

(2) Based on leader growth observations

Table 18 Old-growth definition for another central Oregon species, *Pinus ponderosa*. The lack of required down wood reflects the natural role of fire in the *P. ponderosa* community. Otherwise, typical values are 8 to15 pieces greater than 2.45m long and 30cm in diameter.

Parameter	Amount
Old-growth tree density	25 trees/ha or
	5 trees/ha (late seral)
Minimum diameter	53cm at breast height (DBH) or 79 cm (late seral)
Minimum age	150 years or
	200 years (late seral)
Decadence present	Yes (late seral)
Number of canopies	1
Variation in tree diameters	yes
Standing dead trees	7.5 trees/ha > 36 cm DBH
Down wood	0 pieces/ha
Understory canopy cover	20-40% typical

Relationships between tree age, other tree attributes, and site conditions

J. occidentalis may be the longest-lived plant species in Oregon. Information on the lifespan of the species is only now emerging. Clearly trees over 1000 years of age are not unusual and the upper limit is at least 1600 years, based on these results. From a management perspective, it would be useful to have predictors of tree age based on tree morphology and of community structure based on tree density and site environmental conditions. Such generalizations have proven difficult to make.

It is apparent that tree development occured slowly, probably due to climatic limitations and the inherent physiology of the species. Trees retain the postsettlement growth form, with conical canopy shapes and lateral and terminal leader growth activity, for much longer than expected. Data for *J. occidentalis* in several physiographic provinces of Oregon and Nevada indicate that the conical shape with rapid leader growth generally persists for 200 to 250 years (RF Miller unpublished data). Thus, some trees of old-growth age have not yet achieved an old appearance. The gradual death process that appears to be prevalent presents problems with tree aging. It results in large age discrepancies between outer tissues on different portions of a single tree. Most live trees with the presettlement growth form are partially dead, with limbs and spikes that may have been dead for hundreds of years. The living portion of some trees is reduced to that supported by cambium under strip bark less than 10cm wide. No information is available to determine whether the dead portions of trees began growth before or proximate to the still-living portions of the same trees. Similarly, no information is available on whether the natural death process generally includes a progression to the stripbark stage.

Attempts to correlate tree age with physical attributes, i.e. growth form and dimensions, have not produced useful results. Similarly, low correlations have been found between site tree attributes and environmental parameters. These results were not unexpected given the variability in tree morphology and the closed condition of old-growth stands. Tree morphology appears to be a complex response to environmental conditions. There is some evidence that tree height and tree height:diameter ratio increased with increases in resource availability. Higher values for these parameters occurred at CHE than at CHW, which should be drier because of the west aspect. Higher values also occurred at GMS and GMNi than at the shallow-soiled GMNm. The average proportion of full canopy that was living also varied, probably due to variations in stand ages and in site resources. Evidence that the woodlands are closed to new tree establishment includes the full occupation of the site by juniper roots (distinguishable from other roots in the interspaces by their distinctive purple sheaths), the suppression of understory trees, and the lack of vigorous leaders on canopy trees. Under these closed conditions, tree photosynthetic capacity at a site should be near a maximum level reflecting site resource availability. However, the tree density at which this maximum occurs will depend on tree morphology. Thus, environmental conditions influence tree attributes directly by affecting tree morphology and indirectly by affecting resource availability. This variability overwhelms morphology and age relationships for the limited tree sample studied.

Understory relationships

Tree attributes also proved to have limited predictive capabilities regarding understory characteristics. The only significant relationships that were found were slight declines in perennial grass cover and understory species richness as tree density increased. One area-specific factor affecting these relationships is probably the high pumice content of the soils. The low level of correlation between understory and overstory attributes is also believed to be due in part to stand closure and to the responsiveness of tree morphology to environmental conditions. Since resource utilization by the junipers is not highly correlated with density or cover, the portion of total resources at a site available to the understory cannot have a high correlation with these attributes.

CONCLUSIONS

Some of the western juniper (*J. occidentalis*) woodlands occurring in central Oregon are older than generally believed and are clearly old-growth woodlands. Little has been known about these unique woodlands until now. These ancient woodlands should be identified so that management plans addressing the special qualities of old-growth can be prepared and implemented. Old-growth trees should be protected from anthropogenic disturbance until their resource values are addressed in management plans.

The results of this study can be used as a preliminary guide to the identification of old-growth western juniper woodlands. In the pumice-dominated soils of the aeolian physiographic province of Oregon, stand characteristics are highly location specific. Minimum attributes of the old-growth woodlands are:

- density of 80 old-growth stems per hectare. Old-growth trees can be considered to be those over 16cm in diameter with less than 90% of the canopy complete.
- decadence is present as dead spires, one or more of multiple tree boles dead, large branches dead, or deformed tops.
- trees are slow growing based on leader growth
- canopy cover between 10 and 35% from a single tree canopy
- density of 10 dead trees over 25cm in diameter per hectare
- density of one large piece of downed woody debris per hectare.

Other expected tree attributes include predominance of a presettlement growth form, suppression of smaller trees. Understory cover can be expected to be less than 20%, with up to 15% herbaceous cover and up to 10% shrub cover. Perennial grass cover up to 12% can be expected.

The seven sites studied exhibit various stages of old-growth development and landscape patterns. In the Badlands, old-growth stands occur as one element of a landscape matrix. This area should be considered to be old-growth woodland, even though parts of the landscape do not meet old-growth criteria. The woodland on Green Mountain North consists of rock outcrops supporting old-growth interspersed in a woodland in an early stage of the old-growth condition. This area may be useful for future research into the dispersion mechanisms of western juniper prior to Euro-American disturbance.

Old-growth juniper woodlands in other soils and landscape locations may have different attributes. Further work is needed to develop an old-growth definition that will apply throughout the range of the species.

This work addresses only the structural characteristics of old-growth juniper woodlands. Much more research into the functioning of the systems is needed before we will have even the most basic understanding of them. Some of the areas for further research suggested by this work include nutrient cycling processes, mode of decay and role of woody detritus, stand replacement dynamics, and functional relationships between the tree canopy and understory.

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APPENDICES

APPENDIX 1

Table A1 Species listing, including sites of occurrence.

SPECIES NAME	Species ID	CHE	CHW	HRN	BAD	GMNM	GMNI	GMS
PERENNIAL GRASSES								
Agropyron desertorum	AGDE	x						
Agropyron spicatum	AGSP	x	x	x	x	x	x	x
Carex rossii	CARO			x	x	x	x	x
Elymus cinereus	ELCI				x			
Festuca idahoensis	FEID	x	x	x	x	x	x	x
Koeleria macrantha	KOCR	x	x	x	x	x	x	x
Oryzopsis hymenoides	ORHY	x		x		x		
Poa canbyi	POCA	x						
Poa cusickii	POCU	x						
Poa nevadensis	PONE		x			x	x	x
Poa sandbergii	POSA	x	x	x	x	x	x	x
Poa scabrella	POSC	x						
Sitanion hystrix	SIHY	x	x	x	x	x	x	x
Stipa columbiana	STCO				x			
Stipa occidentalis	STOC			x	x			
Stipa thurberiana	STTH	x	x	x	x	x	x	x
PERENNIAL FORBS								
Achillea millefolium	ACMI	x		x		x	x	
Agoseris glauca	AGGL	x	x	x		x	x	x
Antennaria dimorpha	ANDI	x	x	x	x	x	x	x
Antennaria geyeri	ANGE	x	x					
Antennaria luzuloides	ANLU					x	x	
Antennaria microphylla	ANMI	x	x	x		x		
Arenaria congesta	ARCO2	x						
Arabis holboellii	ARHO					x	x	x
Arabis sparsiflora	ARSP2	x	x	x	x	x		x
Astragalus curvicarpus	ASCU2		x	x			x	x
Astragalus filipes	ASFI	x	x	x		x	x	
Astragalus letiginosus	ASLE	x				x	x	x
Astragalus obscurus	ASOB							x
Astragalus purshii	ASPU	x	x			x	x	

Table A1 Continued

SPECIES NAME	Species ID	CHE	CHW	HRN	BAD	GMNM	GMNI	GMS
Calochortus macrocarpus	CAMA	x	x		x	x		
Crepis acuminata	CRAC	x	x	x	x	x	x	x
Erigeron bloomeri	ERBL		x			x		
Erigeron filifolius	ERFI	x	x	x	x	x	x	
Erigeron linearis	ERLI			x	x	x	x	x
Eriogonum heracleoides	ERHE			x		x	x	
Eriogonum microthecum	ERMI			x	x			
Eriogonum ovalifolium	EROV	x		x	x	x	x	x
Eriogonum strictum	ERST2	x	x	x		x	x	
Eriogonum umbellatum	ERUM	x		x		x	x	x
Eriophyllum lanatum	ERLA			x	x			
Hydrophyllum occidentale	HYOC	x						
Leptodactylon pungens	LEPU	x	x	x	x	x	x	x
Lomatium triternatum	LOTR	x		x		x		
Lupinus argentus	LUAR	x	x			x	x	x
Lupinus caudatus	LUCA			x				x
Orobanche fasiculata	ORFA			x				
Penstemon humillis	PEHU			x				
Penstemon laetus	PELA	x	x		x	x		
Phlox hoodii	PHHO						x	x
Senecio canus	SECA			x	x	x	x	x
Senecio intergerrimus	SEIN					x		
Silene douglasii	SIDO			x				
Silene menziesii	SIME	x	x			x	x	
Zigadenus paniculatus	ZIPA			x				x
Zigadenus venuosus	ZIVE					x		
ANNUAL GRASSES								
Bromus tectorum	BRTE	x	x	x	x	x	x	x
Vulpia microstachys	VUMI				x	x		
ANNUAL FORBS								
Chenopodium douglasii	CHDO	x	x		x	x	x	x
Chenopodium fremontii var. freemontii	CHFR	x		x	x	x	x	

Table A1 Continued

SPECIES NAME	Species ID	CHE	CHW	HRN	BAD	GMNM	GMNI	GMS
Collomia grandiflora	COGR	x		x				
Collomia linearis	COLI	x	x	x				x
Collinsia parviflora	COPA	x	x	x	x	x	x	x
Cryptantha ambigua	CRAM	x	x	x	x	x	x	x
Cryptantha circumscissa	CRCI			x				
Cystopteris fragilis	CYFR				x			
Descurainia pinnata	DEPI	x	x	x	x	x		
Eriastrum sparsiflora	ERSP4			x	x			
Eriogonum vimineum	ERVI	x	x	x				
Gallium bifolium	GABI						x	
Gayophytum diffusum	GADI			x				
Gayophytum ramosissimum	GARA	x	x	x	x	x	x	x
Layia glandulosa	LAGL		x	x	x			x
Linanthus septentrionalis	LISE		x	x		x	x	x
Mentzelia albicaulis	MEAL	x	x	x	x	x	x	x
Microsteris gracillis ssp. humillor	MIGR	x	x	x	x	x	x	x
Mimulus nanus	MINA			x	x			x
Nama densus var. densum	NADED				x			
Phacelia linearus	PHLI	x	x	x	x			
Plectricis macrocera	PLMA			x				
Townsendia florifer	TOFL	x			x	x	x	
SHRUBS								
Artemisia tridentata ssp. vaseyana	ARTRV	x	x	x	x	x	x	x
Chrysothamnus nauseosus	CHNA		x	x	x	x		x
Chrysothamnus viscidiflorus	CHVI		x	x	x	x	x	x
Purshia tridentata	PUTR			x	x			
Ribes cereum	RICE					x		
Symphoricarpos oreophilus	SYOR			x				
Tetradymia canescens	TECA		x	x	x	x	x	x
TREES								
Juniperus occidentalis	JUOC	x	x	x	x	x	x	x

APPENDIX 2

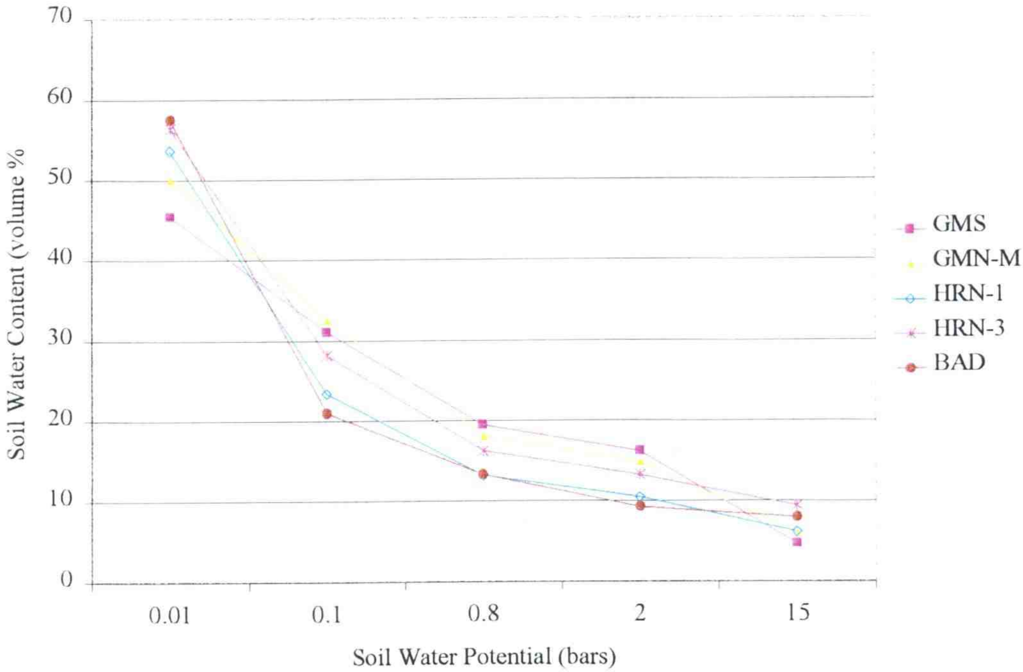

Figure A2 Soil water characteristic function for surface horizon samples. Samples were collected at Green Mountain South (GMS), Green Mountain North-Mounds (GMN-M), Horse Ridge North transects 1 (HRN-1) and 3 (HRN-3) and the Badlands mounds (BAD).