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REVIEW DRAFT

Western Juniper (*Juniperus occidentalis* ssp. *occidentalis*) in the Interior Columbia Basin and Portions of the Klamath and Great Basin: Science Assessment

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Introduction

Western juniper (*Juniperus occidentalis* ssp. *occidentalis*) is a small to medium-statured native tree of the Pacific Northwest Region. Before settlement of the western United States by Europeans, western juniper was predominantly located on mesa edges, ridges, and knolls characterized by fractured bedrock near the surface, and well-drained, shallow soils that produced relatively little understory herbaceous vegetation. These sites were relatively nonpredisposed to fire. Western juniper has increased its acreage approximately 3 to 10X since the late 1800s, and western juniper stands appear denser today compared with the past 5,000 years (Miller and Wigand 1994, R.F. Miller, pers. comm., in Swan 1995). Expansion rates have apparently declined in California and much of Oregon, yet field observations indicate continual rapid expansion on some sites (Eddleman, pers. comm., in Swan 1995). Sites experiencing expansion include some of the more productive rangelands, characterized by riparian communities, mountain big sagebrush, and aspen stands (R.F. Miller, pers. comm. 1995). This expansion and increasing density of western juniper woodlands concerns (1) landowners, (2) county, state, and federal land managers, and (3) scientists. The concerns stem from observed negative effects of western juniper invasion and increasing density on site biodiversity, hydrology (for example water infiltration, water runoff, sediment loss through erosion), site productivity, and wildlife habitat (Eddleman 1995 and Bedell et al. 1993, in Swan 1995). The evidence for these negative effects is based on observations to a large degree, with little controlled experimentation available to provide supporting documentation (Belsky 1996).

Scientists generally agree that some juniper control is essential on sites that did not historically sustain juniper, in order to restore pre-juniper conditions, but how much and where are unresolved questions at present. An additional unresolved question is whether or not western juniper control should be implemented anywhere. Belsky (1996) proposes that the rationale for past, present, and planned western juniper control is faulty or at best should be reexamined, because the proposed ecosystem benefits of western juniper control have not yet been documented unequivocally by science.

The purpose of this assessment is to objectively document the current condition of western juniper woodlands in the Interior Columbia Basin and portions of the Klamath and Great Basin (hereafter referred to as "the Basin"). We first provide a historical (pre European settlement) synopsis of western juniper distribution and causes that affect its distribution. This serves as a foundation for interpretation of current distribution and causes that affect distribution. We will present the state of our knowledge on the effects of western juniper woodlands on resources and processes including watershed hydrology, biodiversity, productivity, and wildlife. Recommendations for management of western juniper woodlands will be presented.

The foundation for this assessment is a scientific assessment of western juniper written by Eddleman et al. (1994) and solicited by the Interior Columbia Basin Ecosystem Management Project. References cited in the text with an asterisk were cited in Eddleman et al. (1994). Pertinent supplementary material from various sources was included also and cited (non-asterisked).

Current Geographical Range

The current geographical range of western juniper includes (a) northern California, from Susanville, Lassen County northward (Vasek 1966*), (b) west of the Cascades from Trinity County, California to southern Jackson county, Oregon, (c) east of the Cascades across Oregon and northward to the Columbia River, into southwestern Idaho on the Owyhee Plateau, and (d) scattered stands in northwestern Nevada and southeastern Washington (Vasek 1966*, Dealy 1990*).

Changes in Western Juniper Woodlands During the Holocene Epoch

Prehistoric Period

Climate during the Holocene epoch (last 12,000 years) has generally been warmer and drier compared with climate during the Pleistocene (Davis 1982*). Compared with present climate, the climate during the Holocene was periodically cooler and wetter, cooler and drier, warmer and drier, or warmer and wetter (Antevs 1938*, Davis 1982*). Season of maximum precipitation apparently varied across the Intermountain sagebrush region during the Holocene (Davis 1982*, Wigand and Nowak 1992*).

Within this general description of Holocene climate, the earliest evidence of western juniper within its historic range of northeastern California and eastern Oregon is between 4,000 and 7,000 years before present (Bedwell 1973*, Mehringer and Wigand 1987*). Precipitation was greater than present between 4,000 and 2,000 years before present (Davis 1982*, Wigand 1987*), temperatures cooled compared with previously, and precipitation was concentrated more in the winter compared with summer (Wigand 1987*). Juniper expanded downslope by as much as 150 m during this cool-wet period (Mehringer and Wigand 1987*, 1990*). Juniper maintained a woodland appearance, with less density than woodlands of today (Miller and Wigand 1994*). Fire probably maintained the open tree structure. A vigorous herbaceous understory apparently was present (Mehringer and Wigand 1987*) that provided fine fuels.

Juniper woodlands apparently retreated upslope (Mehringer and Wigand 1990*, Wigand 1987*) between 1,900 and 1,000 years before present (Wigand 1987*). Climatically, this was a warmer-drier period across the Great Basin (Davis 1982*, Wigand 1987*, Wigand and Nowak 1992*) compared with previously.

Juniper distribution apparently expanded and retracted frequently during the last 1,000 years. Juniper distribution expanded about 1,000 years before present (Wigand 1987*), retracted about 700 and again at 500 years before present, because of major fire and drought events

(Wigand 1987*), and reexpanded about 400-500 years before present in the northern Great Basin (Mehringer and Wigand 1990*), possibly at higher elevations (Mehringer and Wigand 1987*).

Historic Period

The Little Ice Age culminated in the mid 1800s and temperatures have risen since (Ghil and Vautgard 1991*). Western juniper began increasing in density and distribution in the late 1800s (Eddleman 1987a*, Miller and Rose 1995*, Young and Evans 1981*), and has since expanded into open meadows, grasslands, sagebrush steppe communities, aspen groves (Eddleman 1987a*, Miller and Rose 1995*, Young and Evans 1981*), and riparian communities (personal observations by L.E. Eddleman and R.F. Miller). The majority of the present day woodlands in eastern Oregon are less than 100 years old (USDI-BLM 1990*).

Livestock grazing, fire suppression, and climate are the factors most frequently implicated in this historic expansion of juniper throughout the western United States. Climate and fire combined likely were causal in juniper expansion and retraction during prehistoric times, but the integrated effects of livestock grazing, altered fire regimes, and possibly climate change probably are responsible for expansion of western juniper woodlands during the last 100 years.

a. Climate Change

Climatic conditions between 1850 and 1916 in the northern Great Basin were characterized by milder winters and greater precipitation, compared with the current long-term average (Antevs 1938*, Graumlich 1985*, Holmes et al. 1986*). These conditions would promote vigorous juniper growth (Earle and Fritts 1986*, Fritts and Xiangdig 1986*), and increase the potential for juniper establishment. Additionally, increasing atmospheric CO_2 concentrations and the prospect of global warming have been postulated as causal in expansion of pinyon-juniper woodlands in the southwest (Johnson et al. 1990*) because cool season, C_3 plants (for example western juniper) respond more favorably to increased CO_2 levels compared with warm season, C_4 plants (Bazzaz et al. 1985*). Although the understory species in the northern portions of the juniper zone are also cool season species, woody cool season species maintain increased water use efficiencies compared with herbaceous cool season species (Polley et al. 1993*). In the field however, where western juniper growth is constrained by many environmental factors in addition to CO_2 levels, empirical studies have yet to produce evidence that links increased atmospheric CO_2 levels and western juniper expansion (Belsky 1995, 1996).

b. Fire and Livestock Grazing

Fire, specifically reduced fire frequency, has been implicated as causal to juniper expansion (Burkhardt and Tisdale 1976*, Young and Evans 1981*). Western juniper trees up to 4 meters in height are readily killed by fire (Burkhardt and Tisdale 1976*, Martin 1978*, Martin and Johnson 1976*, Quinsey 1984*), whereas larger trees are killed only if heavily scorched or if the cambium is girdled. Fire probably maintained both shrubs and trees at low densities and often restricted trees to harsh sites characterized by little contiguous fuel.

The reduction of fire frequencies in the historic period was probably attributable to a decline in fires set by Native Americans, concurrently with a reduction in fine fuels that were consumed by livestock. Domestic livestock in high densities consumed fine fuels in the late 1800s and early 1900s (Griffiths 1902*, Burkhardt and Tisdale 1976*). This reduction in fine fuels resulted in a decrease in fire return intervals. The reduction in fine fuels coincided with the relatively wet and mild climatic conditions of the late 1800s and early 1900s. Thus the integrated effects of domestic livestock consumption of fine fuels, reduced fire frequency, and climate probably catalyzed the accelerated expansion of western juniper woodlands we see today.

Summary

Prehistoric expansion of western juniper apparently was driven by an increase in annual and growing season moisture and relatively cool temperatures. Expansion was downslope, into the drier Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*) communities. In contrast, western juniper has expanded in historic times during a period of relative aridity, decreasing fire return intervals, a decrease in the proportion of grasses to sagebrush, and introduction of new plant species (for example exotic and noxious weeds). Expansion has been upslope, into the moist mountain big sagebrush steppe communities, and downslope, into more xeric Wyoming big sagebrush and low sagebrush communities. Domestic livestock grazing has been a causal factor in this historic expansion.

The development of the present western juniper woodlands has proceeded under a different set of environmental variables compared with prehistoric woodlands. Stand structure and composition of present woodlands differ from prehistoric woodlands, setting the stage for differential impacts on soil stability and watershed function, nutrient cycling, energy flow, and recovery mechanisms, all of which represent processes on rangelands proposed as integral to an assessment of rangeland health (National Research Council 1994).

Some Life History Characteristics of Western Juniper

Seed

a. Production

Western juniper initiates substantial seed production between 50 and 70 years of age (Eddleman 1984*, Miller and Rose 1995*) and after it attains a height of 2-3 meters (Eddleman 1987*). Prodigious seed production (up to 10,000 berries/tree) has been reported from northeastern California, but most (80%) trees produce 100 or fewer berries, of which most are located at the 2-4 meter height on the outside of the canopy (Lederer 1977*). Temporal variation in seed production and its association with environmental factors exists but remains unquantified.

b. Dissemination

Western juniper relies on seed for reproduction, and seed are disseminated by several agents. Seed can move in water flowing across the soil surface, especially on frozen soil

(Eddleman 1984*), and by downslope (gravity) movement (Burkhardt and Tisdale 1976*). Townsend's solitaire (*Myadestes townsendi*) (Lederer 1977*, Podder and Lederer 1982*), American robin (*Turdus migratorius*), Steller's jay (*Cyanocitta stelleri*), and scrub jay (*Aphelocoma coerulescens*), are primary bird vectors of seed dispersal in the Great Basin (Gabrielson and Jewett 1970*). Seed can also be disseminated by coyotes (*Canis latrans*) and rabbits (species were not mentioned) (Johnsen 1962*).

c. Dormancy-Germination

Most western juniper seed remain dormant and never germinate. Requirements for germination apparently involve some form of prolonged cool-moist stratification, which enhances germination in a cumulative manner from year to year (Young et al. 1988*).

Seedlings

a. Establishment

Seedlings establish predominantly beneath sagebrush plants (Burkhardt and Tisdale 1976*, Eddleman 1987*, Miller and Rose 1993*), but establishment conditions beneath other shrubs and trees appear favorable, and seedlings can establish in bunchgrass plants (Eddleman, pers. comm. 1995). Seedling establishment in juniper stands with a high (for the site) canopy cover, apparently is located mostly beneath older trees (Miller and Rose 1995*). The benefits beneath sagebrush plants appear to arise from protection from environmental stress and increase in nutrient availability. For example, juvenile foliage representative of seedlings is less water use efficient than adult foliage (Miller 1990*, see below also) and the amelioration of vapor pressure deficit beneath sagebrush plants is proposed as beneficial to juvenile physiological vigor. Young junipers of 2 to 20 years old grow faster under sagebrush plants compared with interspace areas (Miller and Rose 1995*).

During favorable soil water conditions, juvenile western junipers (average height 35 cm) outperform more mature individuals because they show higher rates of carbon dioxide assimilation, leaf conductance, and transpiration, greater allocation to foliage and fine root biomass, and lessened investment of biomass and nitrogen per unit of foliage. These physiological processes are associated with the awl-like foliage characteristic of juveniles, and should enhance establishment, early growth, and competitiveness of western juniper. During periods of high vapor pressure deficits and soil moisture, juvenile western junipers do not restrict transpiration to the degree that adult junipers do, thus adult junipers under these conditions are more efficient in water use (Miller et al. 1993*). During periods when soil moisture is limited, carbon dioxide assimilation of juvenile western junipers is depressed, and again, transpiration is not restricted compared with adults. This suggests that establishment, competitive ability, and spread of western juniper is reduced during periods of reduced precipitation (Miller et al. 1993*). In summary, the physiological attributes ascribed to the juvenile, awl-like foliage appear to provide benefits more in wet versus dry periods.

Field observations suggest that competition between juniper and associated species is not a factor inhibiting western juniper seedling establishment (Burkhardt and Tisdale 1976*, Eddleman 1987*, Miller and Rose 1995*). Seedlings appear to establish irregardless of ecological condition of a plant community. Future, controlled studies could clarify the role and extent of herbaceous and shrub competition on western juniper seedling establishment.

There is ample scientific evidence for inhibition of tree and other woody plant establishment and growth by herbaceous understory vegetation (see for example the large body of literature on forest grazing and tree-understory vegetation competition; literature from the pinyon-juniper zone (Evans 1988 and West 1984, in Belsky 1995), and literature from savannahs of Texas and Australia (Archer 1989, Brown and Archer 1989, Archer 1994). Belsky (1995) proposes that livestock grazing on understory herbaceous vegetation diminishes vigor of this vegetation and indirectly accelerates western juniper increase. The large body of literature on forest grazing and tree-understory vegetation competition provides a credible foundation for this view. However, western juniper also is currently invading sites with rather limited or no history of livestock grazing, for example the west face of Hart Mountain and the east face of the Steens, in Oregon (R.F. Miller, pers. comm. 1995). It appears, at our current level of knowledge, that operative mechanisms involved with livestock grazing and western juniper increase relate to the consumption of fine fuels and its resultant effects on reduction in fire frequency and diminishing of plant vigor and competitive potential. Western juniper seedlings can establish with or without livestock grazing, but establishment is accelerated by livestock grazing that results in lowered vigor of understory vegetation.

b. Growth Rates

Seedling growth rates beneath sagebrush plants may be very slow during the first few years. Growth rates of 1.4 to 3.4 cm/yr have been reported (Miller and Rose 1995*, Burkhardt and Tisdale 1976*, Kramer 1990*, Eddleman 1987*). In contrast, Eddleman (1987*) reported growth rates of 9.0 to 16.7 cm/yr for trees over 90 years old within a young woodland.

Root System

Seedlings produce a slowly developing taproot with little lateral root development up to 10 years of age. Lateral root development increases with maturity, with almost 70% of root biomass and 90% of root length in lateral roots of old individuals (oldest being 34 years old) (Kramer 1990*). Roots can penetrate fractured rock (Kramer 1990*). Taproots may degenerate with age, or development may be facultative, because Young and Evans (1984*) did not locate taproots on older trees. Root mass is concentrated near the bole of young, but mature western juniper trees, and is characterized by fine roots. Few roots are found beneath 75 cm in depth (Young and Evans 1984*).

Mortality

Mortality factors apparently are nearly absent from western juniper woodlands. Insects and disease cause little mortality. Growth and survival of western juniper appears to be hampered more by belowground lateral root loss, attributable to disease agents or belowground herbivory, than by aboveground loss of foliage through disease or herbivory (Miller et al. 1991b*). The primary mortality factor operating in western juniper stands is fire. Trees under 2 meters tall are easily killed by fire but as tree height increases, greater fire intensities are required to cause mortality. Stands with a high (for the site) canopy cover burn poorly because fuel is lacking between and beneath canopies (Martin 1978*).

Western Juniper Woodlands

Western juniper communities typically exist as (1) inclusions in the forest zone, (2) old juniper woodlands, and (3) young woodlands that in the recent past have expanded into the sagebrush zone. Present vegetation communities within numbers 1 and 3 appear to be in a state of transition as regards succession. Predicting the future plant communities of present young woodlands is difficult because succession on young western juniper woodlands is not understood well. Sites with young juniper woodlands that are undergoing succession represent an untapped potential for establishment of long-term baseline studies.

Elevation and Precipitation Range

Western juniper exists at elevations from 600 to 6,560 feet (Sowder and Mowat 1958*, Driscoll 1964a*, Rose 1989*, Dealy et al. 1978b*, Miller and Rose 1995*). Precipitation where woodlands exist typically ranges from 250 to 355 mm (9 to 14 in).

Woodland Maturity

Two age groups are recognized for western juniper stands. Old woodlands contain an old tree component. Trees in this component generally exceed 150 years and may attain an age of nearly 900 (Holmes et al. 1986*). Dominant trees in old woodlands are large with flat tops and heavy lower limbs. Younger age classes may be present (Burkhardt and Tisdale 1969*). Young woodlands are dominated by trees less than 100 years old. These trees possess a terminal leader and conical-shaped crowns (Burkhardt and Tisdale 1969*). Old trees are not present.

Current acreage

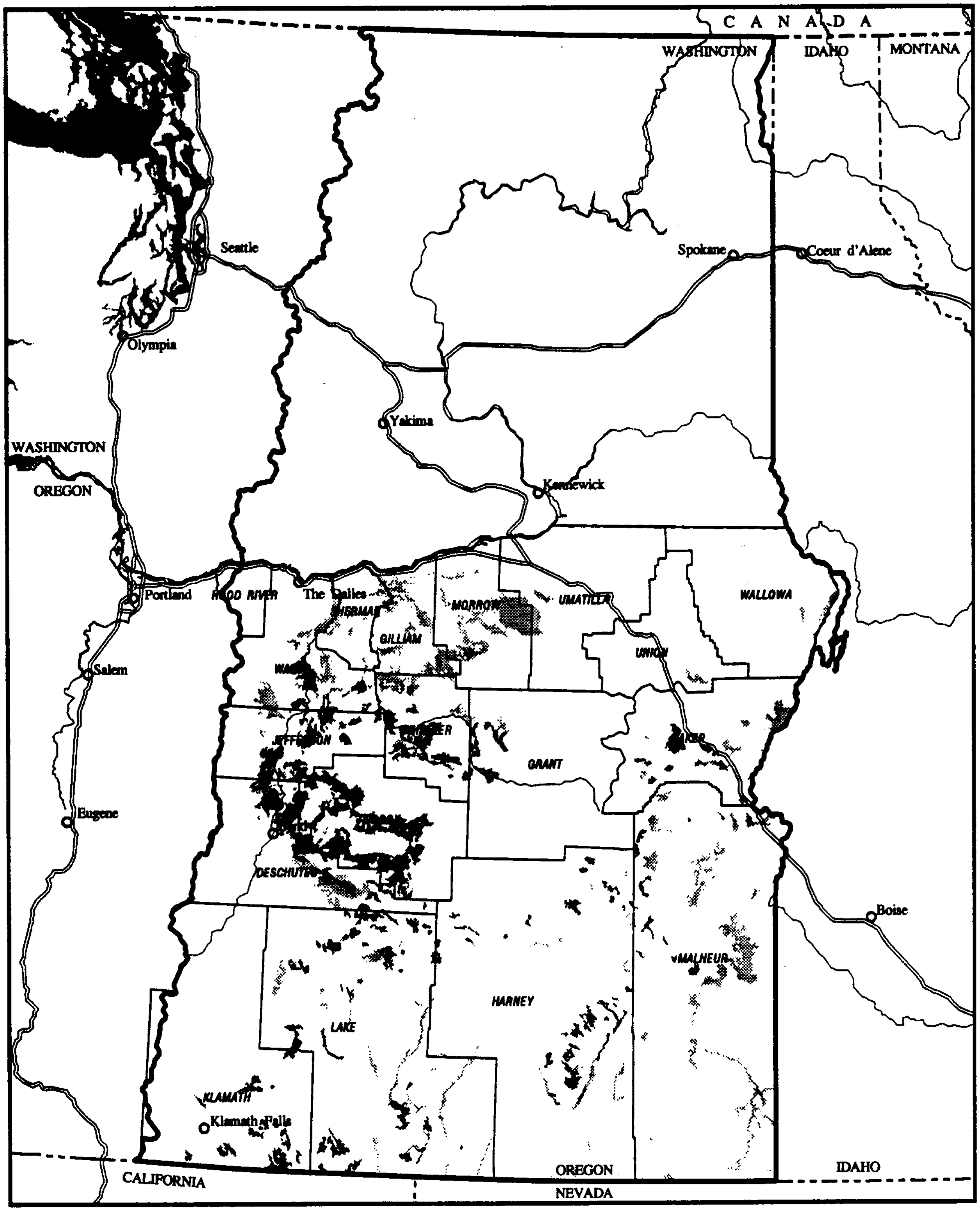
Eddleman et al. (1994) estimate that western juniper woodlands exist on a minimum of 932,000 hectares in Oregon, and approximately 1.614 million hectares total in Washington, Oregon, Idaho, California, and Nevada. Eddleman et al. (1994) used several literature sources to produce these estimates. The Oregon Natural Heritage Program's Gap Analysis Program indicates that the western juniper woodland complex is distributed over about 714,000 hectares in Oregon, within several vegetation cover types (Table 1, Fig. 1). Occasional or isolated western juniper trees are distributed over an additional 606,000 hectares in Oregon, and Fig. 1 does not show the lands currently being invaded by western juniper that are populated by western juniper seedlings. Areal extent and proportion of the total acreage existing in old woodlands and young woodlands is difficult to determine from the literature.

Table 1. Actual vegetation cover types in Oregon that include western juniper as a diagnostic tree species, as mapped by the Oregon Gap Analysis Program (Kagan and Caicco 1992).

Vegetation Cover Type	Acres (Thousands)
Woodlands	
Juniper-big sagebrush-bluebunch wheatgrass	444.3
Juniper-big sagebrush-Idaho fescue	333.2
Juniper-low sagebrush-Idaho fescue	192.0
Juniper-big sagebrush-bitterbrush	164.4
Juniper-big sagebrush-bottlebrush squirreltail-Thurber needlegrass	134.0
Juniper-bunchgrass	95.4
Juniper-low sagebrush-Sandberg's bluegrass	86.7
Juniper-big sagebrush-cheatgrass	86.1
Juniper-bitterbrush-Idaho fescue	68.5
Juniper-low sagebrush-tall bunchgrass	52.9
Juniper-bitterbrush-bluebunch wheatgrass	43.2
Juniper-mountain big sagebrush-Idaho fescue	41.1
Juniper-big sagebrush-Sandberg's bluegrass	13.6
Juniper-Ponderosa pine-big sagebrush	9.6
TOTAL	1,765.0 (714.3 hectares)

Table 1. (continued)

Occasional or Isolated Tree	
Bluebunch wheatgrass-Idaho fescue-Sandberg's bluegrass canyon grassland	697.7
Rimrock and canyon shrubland, with sagebrush	200.9
Big sagebrush ash beds	161.5
Owyhee Uplands canyon, shrubland-grassland	102.5
Big sagebrush-bitterbrush-Idaho fescue	90.8
Big sagebrush-western needlegrass	82.6
Inland sand dunes	36.1
Mountain mahogany-juniper rimrock and canyon slopes	34.8
Curlleaf mountain mahogany	27.4
Big sagebrush-squawapple-Idaho fescue	24.6
Bitterbrush-Idaho fescue and bluebunch wheatgrass and western needlegrass and dry sedges	24.1
Big sagebrush-bitterbrush-bluebunch wheatgrass	15.4
TOTAL	1,498.4 (606.4 hectares)



~~Map 2-36.~~ Fig. 1
Distribution of Western Juniper in Eastern Oregon Counties

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Plant Associations Susceptible to Western Juniper Invasion

An assessment of range site descriptions in use by the Natural Resources Conservation Service for Oregon east of the Cascade Mountains (USDA Soil Conservation Service 1986-1990*) provides evidence for a wide range of plant associations that sustain western juniper or are susceptible to western juniper invasion. In decreasing order of frequency, sites that are dominated by the following species either sustain western juniper or are susceptible to invasion: mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*); basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*); low sagebrush (*Artemisia arbuscula*), and bitterbrush (*Purshia tridentata*) (tie); mountain mahogany (*Cercocarpus ledifolius*); Idaho fescue (*Festuca idahoensis*); ponderosa pine (*Pinus ponderosa*), and bluebunch wheatgrass (*Agropyron spicatum*) (tie); stiff sagebrush (*Artemisia rigida*), and Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) (tie); basin wildrye (*Elymus cinereus*), and threetip sagebrush (*Artemisia tripartita*) (tie).

Soils

Western juniper is apparently not restricted greatly by soil. This species has been found on soils which have developed from sedimentary, igneous, and metamorphic origin parent materials, including rhyolite, andesite, basalt, dacite, saprolite, tuff and tuff breccias, igneous and pumice sands, and alluvial, colluvial, lacustrine, and aeolian mixtures of the above (Burkhardt and Tisdale 1969*; Dealy et al. 1978a*; Driscoll 1964a*, 1964b*; Eckert 1957*; Pomerening et al. 1983*; Vaitkus and Eddleman 1991*; Young and Evans 1981*).

Old woodlands are located typically on mesa edges, ridges, and knolls where fractured bedrock is near the surface and soil depths are shallow. Young woodlands are located typically on valley slopes and bottoms with few rock outcrops. Soils of young woodlands are rather uniform and much deeper than soils of old woodlands (Burkhardt and Tisdale 1969*), and many contain claypans (Pomerening et al. 1983*).

Western juniper woodlands in Oregon have been classified broadly by soil parent material (Driscoll 1964a*). Woodlands existing on soils derived from aeolian igneous and pumice sands, or soils in which these sands are mixed through the horizons, are found in southern Wasco county south into northern Deschutes county, western Crook county, and most of Jefferson county. Dispersed woodlands on these soils are found in southern Deschutes and northwest Lake counties. Woodlands existing on soils derived from sedimentary formations are found in areas along the upper John Day River in Grant and Wheeler counties and in the upper Crooked River and Bear Creek drainages of Crook county. Woodlands existing on soils derived from igneous materials are found in southern Wasco county, Sherman and Wheeler counties, and the North Fork of the John Day River in Grant county. Baldwin (1981*) reported that these latter woodland-soil groupings were found also on the Owyhee Plateau in Idaho, Malheur, Harney, southern Klamath, northwestern and southern Lake counties in Oregon, and northern Modoc county in California.

Although information above relates soils with western juniper distribution, in general, little information exists that relates soils with western juniper populations and productivity. Soils classed as Haplaquolls, Cryoborolls, Argixerolls, Durixerolls, and Haploxerolls (Mollisols), and Durargids and Camborthids (Aridisols) appear to support high densities of western juniper, whereas scattered junipers have been located on Durargids, Haplargids, and Camborthids (Aridisols), Chromoxererts (Vertisol), and some Argixerolls (Mollisol) (Driscoll 1964a*, 1964b*; Green 1975*; Dyksterhuis 1981*; Josaitis 1991*; Lentz and Simonson 1986*; Pomerening et al. 1983*). The very plastic adaptation of western juniper to parent materials and soil types means that western juniper woodlands exist on a very broad group of soil series. Western juniper is not necessarily present on the entire area of any one soil series; certain slopes and phases within series may contain little or no western juniper.

Information is lacking concerning the relationship of juniper establishment and growth with soil chemistry, texture horizonation, and soil depth. Further research into soil calcium and texture might be helpful in understanding western juniper ecology and management, because some soils associated with western juniper apparently are high in calcium (for example Doescher et al. 1987*) and the species shows some affinity for highly calcareous, fine textured soils in Oregon (Anderson 1956*). In summary, we have a more complete knowledge of the soils that western juniper is distributed on than we do the causal mechanisms associated with its distribution on soils or the influence that soil exerts on long-term growth and development of juniper stands.

Empirical studies suggest that amounts of soil nutrients, especially Ca and N, increase beneath the juniper canopy zone as the tree ages, and as compared with intercanopy zones (Doescher et al. 1987*, Josaitis 1991*, Young and Evans 1984*). The causal mechanisms for these observations of nutrient patchiness are unresolved but speculations include (1) a spatial redistribution of nutrients attributable to trees mining the intercanopy zone, (2) an overall increase in nutrients for the site attributable to trees acquiring nutrients from previously unexploited portions of the solum, (3) a reduced nutrient loss from the site attributable to the presence of trees, (4) a capture of nutrients in airborne dust by the canopy, (5) an efficient retention and incorporation of tree-produced organic matter, and (6) certain combinations of the above. An associated unresolved matter is how much of the nutrient patchiness is attributable to the inherent aridity and moisture-supplying capacity of the site and how much is attributable to environmental modification by the woodland trees. Results from Tiedemann and Klemmedson (1995*) for western juniper and Covington and DeBano (1990, in Wilcox and Davenport 1995) for pinyon-juniper woodlands appear to support speculation 1 above, at least for some nutrients.

Juvenile western junipers (average height 35 cm) do not preferentially utilize nitrogen in the form of ammonium, even if ammonium is the dominant form of nitrogen in the soil (Miller et al. 1991a*). Apparently, western juniper is adapted to utilize low ambient levels of soil nitrate nitrogen. The implication here is that western juniper is adapted to tolerate nitrogen-deficient soils.

Density and Canopy Cover

Tree densities and canopy cover vary tremendously by site. In general, higher tree densities for stands with high (for the site) canopy cover are found on mountain big sagebrush sites relative to low sagebrush sites. High densities of trees over 18,000/ha exist on aspen sites on Steens Mountain in southeastern Oregon (Miller and Rose 1995*). Canopy cover is typically greater on moist sites compared with xeric sites.

Declines in understory biomass accompany increases in density of pinyon and juniper in the Great Basin and southwestern United States (Schott and Pieper 1985, 1987; Tausch et al. 1981; Tausch and West 1995; all of these cited in Wilcox and Davenport 1995). This same trend apparently accompanies an increase in western juniper canopy cover too, as many researchers and land managers have observed, but no long term studies conducted pre and post western juniper increase are available to provide documentation. As western juniper density increased in Oregon, bitterbrush and big sagebrush growth were reduced, and density declines in these shrubs were attributable to lack of natural regeneration and natural mortality (Adams 1975*). In contrast, understory biomass production was influenced by juniper tree size in central Oregon, with most species and species groups responding favorably in production as size (and thus canopy diameter) of western juniper increased (Vaitkus and Eddleman 1991*); consistent declines in production of understory species with increasing juniper tree size were not apparent. In this study, heavy livestock grazing was apparent and the authors believed the large trees were acting as refugia for the understory species, protecting them from consumption by livestock.

Fire Effects

Before Euro-American settlement, fire, attributable to lightning or Native Americans, was apparently a common occurrence in western juniper woodlands (Martin and Johnson 1979*, Shinn 1980*). These fires apparently resulted in a landscape characterized by a mosaic of scattered woodlands. Fires burning through old woodlands were spotty and of low intensity (Burkhardt and Tisdale 1976*). Large scale fires were close to 100 years apart in northeastern Nevada (Young and Evans 1981*), and relatively fire-safe areas were noted on upper slopes with a lack of fuels downslope. Perhaps once per century, broad-scale fires eliminated many woodlands, with scattered trees remaining on some upper slopes and rocky break areas (Burkhardt and Tisdale 1969*, 1976*; Caraher 1978*).

Europeans initiated a fire exclusion policy shortly after settlement of the region containing western juniper. This post-settlement fire exclusion, whether caused singly or by combinations of active fire suppression, reduction of understory fuel by grazing, or a warmer and drier climate that produced less fuel (Burkhardt and Tisdale 1976*), appears to be causal in the reexpansion of young woodlands. Eddleman et al. (1994), based on several literature references, maintain that the loss of fuels to carry fire, caused in part by livestock grazing, probably played a larger role in fire frequency reduction than did active suppression.

Biophysical conditions and plant species composition within young western juniper woodlands are in a transitory period because of the shift away from pre-settlement fire frequencies. Martin (1978*) and Martin and Johnson (1979*) suggest that in the absence of fire, with or without grazing, sagebrush-grass communities will become dominated by juniper. If cheatgrass (*Bromus tectorum*) is present as an understory species in western juniper woodlands, fire and grazing can lead to communities with large amounts of cheatgrass. Cheatgrass and medusahead (*Taeniatherum asperum*) are 2 introduced annual grasses that can markedly increase after burning compared with most native species. The potential for these annuals to displace native species represents long-term transitions in plant community structure and data are unavailable on the transition duration or community composition to be expected. Western juniper plant communities on xeric sites, with inherent low plant cover, appear to be the most susceptible to this understory transition to annuals. Because of the invasive potential of these annuals and their potential to modify community composition, reintroduction of fire into areas that have been excluded from fire for a long period might not result in plant assemblages typically associated with pre-settlement fire frequencies. Thus our ability with fire to transform landscapes currently being invaded by western juniper, into a replica of landscapes typically associated with pre-settlement fire frequencies, appears limited.

Evidence is accumulating that western juniper stores sizeable amounts of nutrients in its tissue (Kramer 1990*, Miller et al. 1990*, Larsen 1993*) that fire might partially remove from the site. Aboveground biomass of juvenile and small-adult individuals contains between 72 and 75% of the total plant nitrogen. Aboveground tissue proportions of total plant nitrogen, phosphorous, potassium, calcium, and magnesium, estimated for a western juniper tree 11 meters tall, were 0.82, 0.63, 0.81, 0.65, and 0.71 respectively. Speculation exists that on nutrient-deficient sites that support western juniper woodlands, removal of nutrients by fire can exacerbate an already marginal situation, and "push" the site across a threshold into a more degraded, stable state (Laycock 1991, in Belsky 1995).

Livestock Grazing Effects

A widely held premise is that uncontrolled grazing and the resultant reduction in fuels had a substantial positive effect on western juniper woodland development in the late 1800s into the early 1900s. In the mountain big sagebrush type, vulnerability to western juniper expansion appears to be enhanced where improper grazing is practiced currently or was practiced historically.

Research information on the effect of grazing by domestic livestock on western juniper woodlands is lacking. Only one general study by Dealy et al. (1978a*, 1978b*) has addressed a grazed versus ungrazed situation in a western juniper woodland. Grass cover declined and juniper cover increased on the grazed woodland compared with an ungrazed woodland with similar soils and aspect. Bitterbrush regeneration was absent on the grazed woodland but was present on the ungrazed. The grazing and fire histories were unknown on the sites.

Research data that could be utilized to resolve the differential effects attributable to intensity, season, and duration of grazing on the multitude of sites and plant species groups that exist in western juniper woodlands are not available. Remnant vegetation on sites with long-term heavy grazing where type, class, season of use, etc. are unknown is of little use in understanding grazing influences and developing grazing management strategies. The effects of western juniper trees and grazing generally are inseparable in the literature. Studies clarifying the effects of livestock grazing and the western juniper trees themselves, on community dynamics within western juniper woodlands, have not been completed and should incorporate either (1) a before and after grazing approach on a site or several sites, along with an ungrazed control(s), or (2) comparison of control sites without western juniper, with sites characterized by ongoing western juniper invasion, with livestock grazing absent. An overriding concern with the above is that the interacting effects of fire are not included, which points to the complexity of clarifying the situation when 3 interacting factors (livestock grazing, western juniper, fire) operate.

Wildlife Use

Development of management guidelines for wildlife in western juniper woodlands has been derived from observation of other vegetation communities because there is a lack of research and documentation relating to wildlife, especially non-game, use of western juniper woodlands (Maser and Gashwiler 1977*). Eddleman et al. (1994) report that after an extensive literature search there still remains a lack of information. This lack of information is unfortunate because the western juniper-sagebrush-bunchgrass community type, of 16 community types studied by Maser et al. (1984*), was the third from top in the number of wildlife species it supported that were known to inhabit southeastern Oregon. Vertebrate species known to utilize western juniper woodlands are listed in Table 2.

a. Large Herbivores

Mule deer (*Odocoileus hemionus*) use western juniper woodland communities, more frequently during severe winter conditions (Leckenby and Adams 1986*), when western juniper provides thermal cover. Leckenby et al. (1982*) defined optimal thermal cover for mule deer in the juniper zone as "stands of evergreen or deciduous trees or shrubs, at least 1.5 m tall, with crown closure greater than 75%." Eddleman et al. (1994) state however, that understory vegetation usually declines in western juniper communities as the western juniper canopy cover increases. The encroachment of western juniper into mule deer winter range reduces the forage base available for winter consumption (M. Liverman, in Haugen 1993). Thus, it appears that western juniper woodlands provide beneficial thermal cover but if the woodlands become too dense, understory forage is reduced which detracts from winter range quality. Mountain big sagebrush communities are a more preferred habitat by mule deer during fawning than western juniper woodland communities (Sheehy 1978*). Pronghorn antelope utilize western juniper woodlands very little during winter or spring (Trainer et al. 1983*), and are found most often in sagebrush or other communities with low vegetation structure (Kindschy et al. 1982*). Studies on interrelationships of Rocky Mountain elk with western juniper woodlands are unavailable but studies appear to be warranted because elk are expanding into these woodlands. In addition, wild horses likely utilize western juniper woodlands but studies are not available.

b. Other Large Mammals

See Table 2 for a list of species.

c. Birds

Field investigations of bird use in western juniper woodlands are very limited, and even throughout the pinyon-juniper ecosystem in the West birds have been seldom investigated (Sedgwick 1987*). Several bird species play a role in consumption and dissemination of western juniper berries (see Seed Dissemination under Some Life History Characteristics of Western Juniper). The expansion of western juniper into sagebrush-dominated communities has potential to be deleterious to sage grouse (*Centrocercus urophasianus*) populations because sage grouse are generally associated with low and big sagebrush communities (Call and Maser 1985*, Gregg 1991*, Willis et al. 1993*). Studies designed to determine sage grouse use of sagebrush as western juniper increases in height and density would seem to be imperative to provide documentation for this concern. Studies designed to relate bird densities and composition to western juniper encroachment and removal would also seem imperative to truly evaluate the effect of western juniper expansion in the Basin. In pinyon-juniper communities, bird density declines after pinyon-juniper is cleared (O'Meara et al. 1981*), whereas bird density increases after pinyon-juniper is burned (Mason 1981*).

d. Small Mammals

Eddleman et al. (1994) report that scientific documentation is scarce that relates use of western juniper woodlands by small mammals. In general, small mammal populations increase in pinyon-juniper ecosystems after trees are cleared and tree slash is left on the soil surface (Kundaeli and Reynolds 1972*, O'Meara et al. 1981*, Severson 1986*, Howard et al. 1987*, Sedgwick and Ryder 1987*).

e. Amphibians and Reptiles

See Table 2 for a list of species.

f. Summary

Western juniper communities are highly variable in structure, ranging from open stands with a relatively diverse assemblage of shrubs, grasses, and forbs, to dense juniper woodlands with meager understory vegetation. The relationship between wildlife and juniper density, understory composition, and community structure is defined poorly. Reliance on observations rather than data to characterize vertebrate use of western juniper woodlands has been the rule. The effects of patch cutting, thinning, or potential commercial harvest (Swan 1995) of western juniper woodlands on wildlife use are virtually unknown.

Table 2. Floral and vertebrate taxa observed in western juniper woodlands (from Burkhardt and Tisdale 1969*; Dealy 1978*; Driscoll 1964a*, 1964b*; Rose 1989*; Vaitkus 1986*; Puchy and Marshal 1993*).

Tree	*Juniperus occidentalis* ssp. *occidentalis*	
	Pinus ponderosa	
Shrub	*Artemisia arbuscula*	
	Artemisia tridentata ssp. *tridentata*	
	Artemisia tridentata ssp. *wyomingensis*	
	Artemisia tridentata ssp. *vaseyana*	
	Artemisia rigida	
	Cercocarpus ledifolius	
	Chrysothamnus nauseosus	
	Chrysothamnus viscidiflorus	
	Grayia spinosa	
	Holodiscus dumosus	
	Purshia tridentata	
	Ribes cereum	
	Symphoricarpos oreophilus	
	Tetradymia canescens	
	Tetradymia glabrata	
Sedge	*Carex rossii*	
	Carex geyeri	
	Kobresia simpliciuscula	
Perennial Grass	*Agropyron saxicola*	
	Agropyron smithii	
	Agropyron spicatum	
	Bromus carinatus	
	Danthonia unispicata	
	Elymus cinereus	
	Festuca idahoensis	
	Koeleria cristata	
	Oryzopsis hymenoides	
	Poa ampla	
	Poa bulbosa	

	Poa compressa	
	Poa cusickii	
	Poa pratensis	
	Poa sandbergii	
	Sitanion hystrix	
	Stipa columbiana	
	Stipa comata	
	Stipa occidentalis	
	Stipa thurberiana	
Annual Grass	*Agrostis interrupta*	
	Bromus brizaeformis	
	Bromus japonicus	
	Bromus mollis	
	Bromus tectorum	
	Festuca bromoides	
	Festuca microstachys	
	Festuca octoflora	
	Taeniatherum asperum	
Perennial Forb	*Achillea millefolium*	
	Agoseris glauca	
	Agoseris grandiflora	
	Allium acuminatum	
	Allium douglasii	
	Antennaria rosea	
	Antennaria dimorpha	
	Arabis hoboelii	
	Arabis puberula	
	Arabis sparsiflora	
	Aster campestris	
	Astragalus beckwithii	
	Astragalus curvicarpus	

	Astragalus filipes	
	Astragalus lentiginosus	
	Astragalus purshii	
	Astragalus reventus	
	Astragalus stenophyllus	
	Balsamorhiza careyana	
	Balsamorhiza sagittata	
	Calochortus macrocarpus	
	Castilleja applegatei	
	Castilleja chromosa	
	Chaenactis douglasii	
	Cheilanthes gracillima	
	Cirsium arvense	
	Crepis acuminata	
	Crepis intermedia	
	Erigeron bloomeri	
	Erigeron elegantulus	
	Erigeron filifolius	
	Erigeron linearis	
	Erigeron poliospermus	
	Erigeron pumilus	
	Eriogonum heracleoides	
	Eriogonum microthecum	
	Eriogonum niveum	
	Eriogonum ovalifolium	
	Eriogonum sphaerocephalum	
	Eriogonum strictum	
	Eriogonum thymoides	
	Eriogonum umbellatum	
	Eriophyllum lanatum	
	Fritillaria pudica	

	Geum campanulatum	
	Hydrophyllum capitatum	
	Leptodactylon pungens	
	Linum perenne	
	Lithophragma bulbifera	
	Lomatium canbyi	
	Lomatium cous	
	Lomatium macrocarpum	
	Lomatium triternatum	
	Lupinus caudatus	
	Lupinus laxiflorus	
	Lupinus lepidus	
	Mertensia longiflora	
	Microseris nutans	
	Microseris troximoides	
	Orobanche uniflora	
	Penstemon humilis	
	Penstemon gracilis	
	Penstemon laetus	
	Penstemon richardsoni	
	Penstemon speciosus	
	Petalostemon ornatum	
	Phacelia hastata	
	Phlox douglasii	
	Phlox hoodii	
	Phlox longifolia	
	Potentilla glandulosa var. *intermedia*	
	Ranunculus occidentalis	
	Senecio canus	
	Senecio integerrimus	
	Sisyrinchium douglasi	

	Sisyrinchium idahoense	
	Stellaria americana	
	Stellaria nitens	
	Trifolium dubium	
	Trifolium macrocephalum	
	Trifolium microcephalum	
	Zygadenus paniculatus	
Annual, Biennial Forb	*Alyssum desertorum*	
	Amsimkia intermedia	
	Blepharipappus scaber	
	Clarkia pulchella	
	Coldenia grandiflora	
	Collinsia parviflora	
	Collomia grandiflora	
	Cordylanthus ramosus	
	Cryptantha affinis	
	Cryptantha ambigua	
	Descurainia pinnata	
	Descurainia richardsonii	
	Draba verna	
	Epilobium minutum	
	Epilobium paniculatum	
	Eriogonum vimineum	
	Erodium cicutarium	
	Euphorbia spp.	
	Galium bifolium	
	Gayophytum humile	
	Gayophytum nuttallii	
	Hemizonia pungens	
	Holosteum umbellatum	
	Lactuca ludoviciana	

	Lagophylla ramosissima	
	Layia glandulosa	
	Lepidium perfoliatum	
	Linanthus harknessi	
	Lupinus microcarpus	
	Madia gracilis	
	Madia sativa	
	Microsteris gracilis	
	Mimulus breweri	
	Montia perfoliata	
	Navarretia sp.	
	Orthocarpus tenuifolius	
	Phacelia linearis	
	Plectritis macrocera	
	Polemonium micranthum	
	Polygonum majus	
	Ranunculus testiculatus	
	Ranunculus occidentalis	
	Sanguisorba minor	
	Sisymbrium altissimum	
	Taraxacum ceratophorum	
	Tragopogon dubius	
	Verbascum thapsus	
Amphibian	Long-toed Salamander, *Ambystoma macrodactylum*	X[1]
	Pacific Treefrog, *Pseudacris regilla*	X,F
Reptile	Rubber Boa, *Charina bottae*	X
	Racer, *Coluber constrictor*	X
	Sharp-tailed Snake, *Contia tenuis*	X
	Western Rattlesnake, *Crotalus viridis*	X
	Southern Alligator Lizard, *Elgaria multicarinatas*	X,F
	Western Skink, *Eumeces skiltonianus*	X

	Night Snake, *Hypsiglena torquata*	X
	Striped Whipsnake, *Masticophis taeniatus*	X
	Short-horned Lizard, *Phrynosoma douglassi*	X,F
	Gopher Snake, *Pituophis melanoleucus*	X
	Sagebrush Lizard, *Sceloporus graciosus*	C,F
	Western Fence Lizard, *Sceloporus occidentalis*	X
	Side-blotched Lizard, *Uta stansburiana*	X
Bird	Cooper's Hawk, *Accipiter cooperii*	F
	Sharp-shinned Hawk, *Accipiter striatus*	F
	Chukar, *Alectoris chukar*	I,G,R,F
	Golden Eagle, *Aquila chrysaetos*	R,F
	Long-eared Owl, *Asio otus*	R,F
	Cedar Waxwing, *Bombycilla cedrorum*	F
	Bohemian Waxwing, *Bombycilla garrulus*	F
	Great Horned Owl, *Bubo virginianus*	R,F
	Red-tailed Hawk, *Buteo jamaicensis*	R,F
	Rough-legged Hawk, *Buteo lagopus*	F
	Ferruginous Hawk, *Buteo regalis*	R,F
	Pine Siskin, *Carduelis pinus*	F
	House Finch, *Carpodacus mexicanus*	R,F
	Turkey Vulture, *Cathartes aura*	R,F
	Canyon Wren, *Catherpes mexicanus*	R,F
	Common Nighthawk, *Chordeiles minor*	R,F
	Northern Flicker, *Colaptes auratus*	R,F
	Common Raven, *Corvus corax*	R,F
	Steller's Jay, *Cyanocitta stelleri*	F
	Yellow-rumped Warbler, *Dendroica coronata*	F
	Black-throated Gray Warbler, *Dendroica nigrescens*	R,F
	Townsend's Warbler, *Dendroica townsendi*	F
	Dusky Flycatcher, *Empidonax oberholseri*	R,F
	Gray Flycatcher, *Empidonax wrightii*	R,F

	Horned Lark, *Eremophila alpestris*	R,F
	Prairie Falcon, *Falco mexicanus*	R,F
	American Kestrel, *Falco sparverius*	R,F
	Northern Pygmy Owl, *Glaucidium gnoma*	R,F
	Pinyon Jay, *Gymnorhinus cyanocephalus*	R,F
	Cliff Swallow, *Hirundo pyrrhonota*	F
	Barn Swallow, *Hirundo rustica*	F
	Northern Shrike, *Lanius execubitor*	F
	Loggerhead Shrike, *Lanius ludovicianus*	R,F
	Townsend's Solitaire, *Madestes townsendi*	F
	Ash-throated Flycatcher, *Myiarchus cinerascens*	R,F
	Sage Thrasher, *Oreoscoptes montanus*	R,F
	Mountain Chickadee, *Parus gambeli*	R,F
	Common Poorwill, *Phalaenoptilus nuttallii*	R,F
	Black-billed Magpie, *Pica pica*	R,F
	Green-tailed Towhee, *Pipilo chlorurus*	R,F
	Bank Swallow, *Riparia riparia*	F
	Rock Wren, *Salpinctes obsoletus*	R,F
	Rufous Hummingbird, *Selasphorus rufus*	F
	Mountain Bluebird, *Sialia currucoides*	R,F
	Burrowing Owl, *Speotyto cunicularia*	R,F
	Brewer's Sparrow, *Spizella breweri*	R,F
	Northern Rough-winged Swallow, *Stelgidopteryx serripennis*	F
	European Starling, *Sturnus vulgaris*	I,R,F
	Tree Swallow, *Tachycineta bicolor*	F
	Violet-green Swallow, *Tachycineta thalassina*	F
	American Robin, *Turdus migratorius*	F
	Western Kingbird, *Tyrannus verticalis*	F
	Mourning Dove, *Zenaida macroura*	G,R,F
Mammal	Pallid Bat, *Antrozous pallidus*	X
	Coyote, *Canis latrans*	X

	Ord's Kangaroo Rat, *Dipodomys ordii*	X
	Domestic Horse (Feral), *Equus caballus*	I,X
	Common Porcupine, *Erethizon dorsatum*	X
	Mountain Lion, *Felis concolor*	G,X
	Silver-haired Bat, *Lasionycteris noctivagans*	X
	Black-tailed Jackrabbit, *Lepus californicus*	X
	Bobcat, *Lynx rufus*	F,X
	Long-tailed Weasel, *Mustela frenata*	X
	Western Small-footed Myotis, *Myotis ciliolabrum*	X
	Long-eared Myotis, *Myotis evotis*	X
	Little Brown Myotis, *Myotis lucifugus*	X
	Long-legged Myotis, *Myotis volans*	X
	Yuma Myotis, *Myotis yumanensis*	X
	Bushy-tailed Woodrat, *Neotoma cinerea*	X
	Mule or Black-tailed Deer, *Odocoileus hemionus*	G,X
	Northern Grasshopper Mouse, *Onychomys leucogaster*	X
	Mountain (or Bighorn) Sheep, *Ovis canadensis*	G,X
	Great Basin Pocket Mouse, *Perognathus parvus*	X
	Deer Mouse, *Peromyscus maniculatus*	X
	Pinon Mouse, *Peromyscus truei*	X
	Townsend's Big-eared Bat, *Plecotus townsendii*	X
	Golden-mantled Ground Squirrel, *Spermophilus lateralis*	X
	Townsend's Ground Squirrel, *Spermophilus townsendii*	X
	Mountain Cottontail, *Sylvilagus nuttallii*	X
	Yellow-pine Chipmunk, *Tamias amoenus*	X
	Least Chipmunk, *Tamias minimus*	X
	American Badger, *Taxidea taxus*	X

[1] X = General community or habitat in which found, I = Introduced, G = Game Species, C = Used for cover, F = Used for feeding, R = Used for Reproduction

Biodiversity Effects

Eddleman et al. (1994) compiled information from several literature sources and report that 1 tree (ponderosa pine), 13 shrub, 3 sedge, 20 perennial grass, 9 annual grass, 82 perennial forb, and 48 annual and biennial forb taxa exist commonly in western juniper woodlands (Table 2). The authors propose that this list is incomplete and knowledge of the autecology and synecology of many of these species in western juniper communities is lacking or inadequate. In addition to flora, 2 amphibian, 13 reptile, 53 bird, and 29 mammal taxa utilize western juniper communities (Table 2). Species lists of non-vascular species, invertebrates or microorganisms were not presented, undoubtedly because information on these groups has not been compiled. Thus, complete estimates of species diversity on sites, pre and post western juniper presence, have not been provided yet. Although some (for example Belsky 1995) propose that western juniper does not reduce biodiversity, credible scientific evidence in support or refutation of this topic just is not available at this time. Biodiversity is scale dependent, and at the landscape scale, it is perhaps appropriate to consider that western juniper woodlands, as a contributor to the mosaic of plant communities on the landscape, add rather than detract from landscape biodiversity. However, there presumably is a threshold beyond which the expansion of western juniper woodlands is not conducive to enhancement of landscape biodiversity. The scale of measurement must be addressed in any quantification of western juniper's effects on biodiversity.

There is no question that western juniper woodlands provide necessary habitat for some vertebrate, floral, and invertebrate species. However, western juniper invasion of mountain big sagebrush, riparian, and other rangeland vegetation types poses a threat to habitat requirements of the various species that depend on those types. This invasion modifies site biodiversity and landscape biodiversity in absolute and relative ways that we do not understand. Whether we permit continual expansion of western juniper woodlands or not, the dilemma from a biodiversity perspective relates to how much acreage of western juniper woodlands of various densities we would like to maintain on the landscape to sustain total biodiversity. Biodiversity within western juniper woodlands would be expected to change as these woodlands age, because density and canopy cover will increase somewhat with age, understory herbaceous and shrub production can decline, and therefore structural layering of habitat can decline. The sentiment at present is that healthy western juniper woodlands, with a full complement of understory vascular (herbs, shrubs, and grasses) and non-vascular species, represent one of the most diverse plant communities in the Pacific Northwest. However, floral diversity, and thus presumably biodiversity, is reduced on sites where western juniper has increased in density to the point that understory vegetation is excluded.

Hydrological Effects

Hydrologic processes play dominant roles in sustaining site stability and productivity in western juniper woodlands. The processes of particular interest include interception of precipitation, infiltration of water, runoff, and erosion. Grazing, burning, and wood harvesting individually and collectively modify these processes and in so doing, redistribute water, sediments, and nutrients.

a. Interception

Interception can be defined as the collection and redistribution of precipitation to the ground or back to the atmosphere by living and dead vegetation. Dead vegetation includes standing dead and litter on the soil surface. Canopy interception, litter interception, throughfall, and stem flow are the usual components of the interception process. Stem flow is the precipitation collected by the canopy that flows down the stem to the soil. Stem flow on western juniper trees represents only a minor proportion of incident precipitation, but because it is concentrated around the bole base it is considered to be of some importance (Young and Evans 1984*). Throughfall is the precipitation that penetrates the canopy or drips from the foliage and branches. Throughfall through western juniper trees is low at the bole, higher midway between the bole and canopy edge, and higher still at the canopy edge (Young and Evans 1984*). Canopy interception by western juniper is dependent on gross precipitation of storm events and canopy cover. Larsen (1993*) calculated canopy interception of 7.8% to 12.8% of incident precipitation for canopy coverages ranging from 9% to 43%. The rate of increase in canopy interception declines with increasing canopy cover, apparently attributable to a decline in foliage density with increasing tree density and cover. Litter interception is potentially very high because litter of western juniper can hold substantial amounts of water, approximately 1 mm of water for every 3 mm depth of litter (Larsen 1993*). However, juniper litter is highly unwettable when dry (Scholl 1971*, Larsen 1993*), yet precipitation readily moves through cracks that have developed in dry litter (Larsen 1993*). In summary, it is apparent that western juniper trees can restrict precipitation input into the soil, more so with low intensity storm events than with high intensity storm events.

b. Infiltration

Infiltration affects storage of soil water in the profile. Water that does not infiltrate runs off the site or evaporates into the atmosphere. Measured infiltration rates in arid and semiarid ecosystems customarily show a high degree of variation, and those measured on western juniper woodlands are no exception. Several factors contribute to that variation, including grass production, litter production, total ground cover, soil texture, soil moisture, bulk density, and total porosity (Williams et al. 1972*, Wood et al. 1987*). Wilcox et al. (1988*) concluded that vegetation cover and aboveground biomass influenced infiltration strongly. Vegetation cover was a positive influence because it decreased flow velocity, increased surface roughness, increased infiltrability through root activity and organic matter additions, reduced raindrop energy, and reduced formation of impermeable crusts. The implication here is that infiltration can be reduced on western juniper woodlands in intercanopy zones where herbaceous and shrub cover has declined.

Infiltration rates typically decline with time, reaching a terminal rate (Wood 1988*). Infiltration rates of soils at field capacity are less than those for the same soils when dry (Blackburn and Skau 1974*). Eddleman et al. (1994) propose that determination of terminal infiltration rates on soils of western juniper woodlands, across a broad range of conditions where controlling variables are identified, is critical to permit prediction of sediment production as a function of site change. Studies are needed that address the terminal infiltration rates and sediment production on soils, pre and post western juniper encroachment, on the same site. In this manner one may ascertain the effect of western juniper on sediment production and erosion.

c. Runoff, Erosion, and Sedimentation

Surface runoff is the antithesis of infiltration. Surface runoff does not always carry sediment, and sedimentation from an upper to a lower site can be caused by natural processes as well as human-influenced processes, and should not always be considered deleterious (Gifford 1985, in Wilcox and Davenport 1995). Sediment production is related strongly to those factors that influence infiltration, plus other factors that relate to erodibility of the soil surface. Therefore, sediment production tends to be inversely related to plant cover and aboveground biomass and positively related to bulk density, slope, and vesicular crusts (Blackburn 1973*, Blackburn and Skau 1974*, Wood et al. 1987*, Wood 1988*).

Sediment yields within western juniper woodlands differ dramatically between habitat types (Buckhouse and Mattison 1980*). Sediment yields from western juniper woodlands can be significantly greater compared with grasslands, but not as compared with sagebrush types (Gaither 1981*). Sediment yields are positively related to moisture content of the soil surface, and yields are higher from soils at field capacity than the same soils when dry (Blackburn and Skau 1974*). Sediment yields in pinyon-juniper woodlands in northern New Mexico are apparently greater on xeric (characterized by south facing slopes and shallow soils) sites compared with more mesic sites, and Wilcox et al. (1995, in Wilcox and Davenport 1995) maintain that this is attributable to less understory cover on the xeric sites. With caution, Wilcox et al. (1995, in Wilcox and Davenport 1995) propose that this process might be operative in western juniper woodlands too, where xeric sites would be more susceptible to erosion than more mesic sites. Based on work of Gifford (1973*, 1975a in Wilcox and Davenport 1995) and Wood and Javed (1991, in Wilcox and Davenport 1995), sediment yields are greater on juniper woodland areas that have been chained and windrowed compared with intact woodlands, and erosion and runoff are greater if slash and debris are removed. Sediment yields on juniper woodland that have been chained with debris left in place are similar to intact woodlands. Causal factors in the increased runoff and sediment yield on the chained and windrowed juniper woodland are destruction of microbiotic soil crusts and increased surface area contributing to runoff, compared with the intercanopy zones which contributed in the intact woodland. Severe disturbance (that is, physical removal of vegetation, microbiotic crusts, litter, and rock) in intercanopy zones in pinyon-juniper woodlands results in greater sediment yield compared with intercanopy zones that have not been disturbed (Wilcox 1994*). Most runoff was observed in mid summer and late winter.

Mid summer runoff in pinyon-juniper woodlands, characterized by often high sediment loads, is generated from high intensity storms, whereas late winter runoff, characterized by often low sediment loads, is frozen soil runoff generated from snowmelt, rain-on-snow, or low intensity winter and spring storms (Wilcox 1994, in Wilcox and Davenport 1995). The majority of the yearly runoff is generated in summer. In addition, runoff and erosion appear to be scale dependent. Water and sediment movement is appreciable within a hillslope, with little loss of sediment from the hillslope (that is, off-site). Extrapolating these results to western juniper woodlands in the Pacific Northwest should be performed with caution because high intensity summer storms are somewhat less typical in the western juniper region. Based on results from studies performed on sagebrush sites on the Reynolds Creek Experimental Watershed in southwestern Idaho, Wilcox and Davenport (1995) surmise that most runoff in western juniper woodlands is frozen soil runoff that is generated from snowmelt and rain-on-snow events, in contrast to runoff in pinyon-juniper woodlands. However, Eddleman et al. (1994) maintain that snowcover in western juniper woodlands typically is not present for long durations. Wilcox and Davenport's (1995) conclusions regarding runoff and erosion are speculative and are (1) erosive energy of precipitation events, or erosivity, in western juniper woodlands is such that little sediment yield and erosion should be expected, (2) runoff and erosion that does result is concentrated more in the intercanopy zones where raindrop impact is present, especially if understory cover is sparse and bare soil is abundant, and (3) although runoff and erosion might be higher locally as a result of juniper expansion, the off-site impacts are likely to be minimal. Redistribution and depositing of sediments on site, in riparian areas, might be beneficial at the ecosystem scale (Gifford 1985, in Wilcox and Davenport 1995). An exception is when channel erosion occurs, which might result in increased erosion as scale increases, and substantial off-site redistribution.

Livestock grazing undoubtedly can be a contributory factor to runoff and erosion within western juniper woodlands, but specifics regarding grazing intensity and its relation to plant cover, microbiotic crusts, soil compaction, etc. in western juniper woodlands have not been documented. In pinyon-juniper woodlands, Evans (1988, in Belsky 1996) attributed excessive rates of runoff and sediment production to overgrazing and other human uses, which reduced herbaceous cover. The effects of livestock grazing and western juniper on runoff and erosion are confounded and require resolution.

Wood (1988*) maintains that the relationship of plant cover to density is a critical factor in interpretation of runoff. As plant cover is comprised of lower plant density, runoff pathways on the soil surface are concentrated, resulting in increased runoff and erosion. Eddleman et al. (1994) propose that expansion of western juniper into sagebrush-grass communities results in a potential reduction of plant densities and coalescing of cover. Research designed to estimate runoff and sediment yield as related to plant density and cover has not been performed and would be useful.

Difficulties arise when attempting to ascribe infiltration and sedimentation research results to western juniper woodlands. These difficulties include

(1) Detailed documentation of the factors that are contributory to the variation in infiltration and sedimentation estimates often are lacking because detailed measurements of soils and vegetation often are lacking. Elucidation of these contributory factors might require the use of small plots and simulated rainfall,

(2) However, use of small plots, usually less than 1 m^2 in size, negate the possibility of interpreting and applying the results of infiltration and sedimentation studies to the site or landscape level (Wilcox and Davenport 1995) because small plot studies estimate overland flow but not subsurface flow, which is a component of watershed runoff. Small plots cannot accommodate the larger scale interaction of biophysical factors that contribute to infiltration and sedimentation, and

(3) Our knowledge of woodland hydrology lacks a seasonal (November through May) period of data, owing to the paucity of studies that have been performed during this period. The November through May period is a period of major moisture input for areas where western juniper woodlands exist.

Wilcox and Davenport (1995) propose that although hydrological studies pose difficulties, erosion measurements need not require expensive investments in experimental watersheds. Several "low tech" techniques they have used include erosion bridges (permanently marked locations where repeated measures of microtopography are made), dating of exposed tree roots, measuring sediments stored on hillslopes, and surveys for gullies or stream channels. These techniques show potential for land managers to pinpoint active erosion on western juniper woodlands.

Conversion

On western juniper woodlands in Oregon existing on lands exclusive of National Forests, less than 1,600 hectares/yr in the last 10 years have been treated to accomplish control (various sources, including Bureau of Land Management, County Extension Offices, and Agricultural Stabilization and Conservation Service Offices). Wildfire is not included in these estimates. Conversely, Oswald (1990*) indicates a general rate of western juniper woodland expansion of about 7,000 hectares/yr in Oregon, on lands exclusive of National Forests, over the last 3 decades. This estimate is exclusive of stands roughly 30 years old or less. From these rough estimates it is apparent that western juniper woodlands are increasing faster than they are being converted in Oregon.

Research conducted in western juniper woodlands to date provides incomplete guidelines for selection of western juniper woodlands to treat, proper treatment once selection is accomplished, and best follow-up management practices. Therefore, guidelines have by necessity been derived from the knowledge base accumulated from semiarid woodland ecosystems in general.

a. Understory Vegetation Response

Production of understory vegetation increases greatly after western juniper trees are killed (Evans and Young 1985*, 1987*; Vaitkus 1986*; Vaitkus and Eddleman 1987*). Understory response can be species specific however (Rose 1989*, Rose and Eddleman 1994*), and varies with location relative to the canopy, initial canopy cover of juniper, species available, time for response, and tree size. Production of understory vegetation, especially squirreltail, Sandberg's bluegrass, total perennial grasses, and total grasses, increased after removal of western juniper from ponderosa pine zones, but 2 perennial grasses, bluebunch wheatgrass and Idaho fescue, did not respond after juniper removal. Understory production increases in the canopy and intercanopy zones after juniper treatment with picloram in northeastern California, but the most rapid and greatest absolute production response is at the canopy edge (Evans and Young 1985*, 1987*). Litter accumulation beneath the canopy appears to retard understory vegetation response temporarily, until the litter decomposes and releases nitrogen. Understory vegetation production is directly related to total soil nitrogen that increases through time after treatment of the juniper. Available soil water increases in areas treated for juniper compared with untreated areas (Evans and Young 1985*).

Although production of understory vegetation increases after western juniper control, the species that respond favorably are not always desirable and the positive recovery response is species-specific (Evans and Young 1985*, Vaitkus 1986*, Vaitkus and Eddleman 1987*). Cheatgrass and medusahead production increased greatly after western juniper control, but perennial grasses did not respond and perennial herbaceous species as a group either did not respond to treatment or declined. The perennial species were sparse on-site pre-treatment (Evans and Young 1985*). Cheatgrass and squirreltail, annual forbs, perennial forbs, and annual grasses other than cheatgrass showed increases in production after western juniper removal in central Oregon (Vaitkus 1986*, Vaitkus and Eddleman 1987*).

To a certain extent, the understory vegetation response post-conversion of western juniper woodlands appears to be contingent on the pre-conversion species present on site (in other words, you get what you had). On sites where cheatgrass and/or medusahead (and probably noxious weeds too) are present pre-treatment, the selection of conversion treatment(s) will probably dictate whether the conversion results in achievement of understory vegetation objectives. Fire might be detrimental to achieving these objectives (see Western Juniper Woodlands, Fire Effects above) whereas the stepwise strategy of broadcast seeding of desirable forage species, tree cutting, and slash dispersal on site shows potential to be more effective (see Revegetation Post-Conversion below).

b. Site Nutrients

Eddleman et al. (1994) propose that for western juniper woodlands, stand conversion that results in whole tree removal should be considered carefully on a site-specific basis. Especially on mineral deficient sites, whole tree removal might not be wise because this represents a mining of nutrients off-site for sites that might be critically limited in nutrients already. Aboveground portions of western juniper trees can accumulate sizeable contents of minerals, for example nitrogen, phosphorous, potassium, calcium, and magnesium (Miller et al. 1990*, Larsen 1993*, and Kramer 1990*). In addition, as western juniper trees age the proportion of total biomass that is aboveground exceeds 50% (Kramer 1990*, Miller et al. 1990*, Larsen 1993*), thus it appears that from a whole tree perspective, more of the carbon is aboveground than belowground. Research, however, has yet to provide estimates of yearly withdrawal of nutrients by growing western juniper trees, nutrients that conceivably are not available for assimilation by associated species. In addition, removal of these nutrient stores attributable to fire (prescribed or natural) or commercial harvest (see Commercial Harvest on Private Land below) is proposed here as potentially deleterious on some sites, especially on sites where nutrients are in relatively short supply. Research has yet to provide estimates of nutrient removal that are attributable to burning or commercial harvest practices in western juniper stands. This research is needed to aid land managers in site-specific decision-making regarding conversion of western juniper and its effects on site nutrients.

c. Sediment Yield, Water Yield Response

Conversion of western juniper woodlands has been promoted to increase water yield and decrease erosion and sediment yield. One of the major hypotheses driving past studies of effects of conversion of pinyon-juniper woodlands (for example Collings and Myrick 1966; Clary et al. 1974; Baker 1982, 1984; all of these cited in Wilcox and Davenport 1995) was that water yield would increase (Wilcox and Davenport 1995). Conversion treatments employed, including herbicide application and mechanical removal, had little effect on runoff and erosion. Little if any increase in water yield resulted from pinyon-juniper removal in Arizona.

Most runoff in western juniper woodlands is surmised to be generated in winter and early spring, when soils are frozen (see Hydrological Effects section above). This runoff typically has a low sediment yield. Perhaps it is premature to assume that conversion of western juniper woodlands will result in decreased erosion and sediment yield. Wilcox and Davenport (1995) propose that there are compelling reasons to reduce juniper in some locations, but improvement in water quality is not a compelling reason.

d. Chemical Treatment

Chemical control of western juniper is possible but results appear to be site specific and certain associated species succumb to the treatment also. Western juniper mortality was low after aerial application of tebuthiuron pellets in eastern Oregon on a western juniper/low sagebrush site, but mortality of understory species was high except for cheatgrass and big sagebrush (Britton and Sneva 1981*).

e. Fire

Used as a conversion treatment, fire should be evaluated on a site-specific basis because its utility in regard to achievement of objectives varies by site. Fire and its effects have been discussed in several portions of this paper (see Western Juniper Woodlands -- Fire Effects; Conversion -- Understory Vegetation Response, and Site Nutrients). Fire (natural and prescribed) can be a valuable management tool for achieving a desirable proportion of woodland, sagebrush steppe, and other vegetation types on the landscape (Bunting 1995). Fire especially is effective for control of western juniper on sites where it is encroaching (sagebrush-grass for example) and its use should be promoted on these sites. However, on sites that sustain western juniper woodlands with large western juniper and a meager understory, mortality and removal of western juniper with fire appears possible only under extreme fire conditions (Martin and Johnson 1979*). Because of this and the proposed negative effects that fire on these sites has on nutrient cycling, fire is not recommended as a conversion tool on these sites. The use of fire as a conversion tool on western juniper woodlands that contain the annual grasses cheatgrass and medusahead, or noxious weeds, in the understory, is risky at best if the objective is to restore the native understory vegetation. Its use on these sites is not recommended unless post-fire, revegetation strategies are planned.

f. Revegetation Post-Conversion

Revegetation of western juniper woodlands after control treatments has been attempted to provide seasonal forage (Leckenby and Toweill 1983*) or to replace or prevent annual grass dominance (Young et al. 1985*, Evans and Young 1987*). Wheatgrasses, for example crested, Siberian, and intermediate, and alfalfa, can establish successfully with drilling, but establishment of other species including smooth brome, basin wildrye, sheep fescue, canby bluegrass, small burnet, sainfoin, clear milkvetch, big sagebrush, fourwing saltbush, bitterbrush, and mountain mahogany, by seeding or transplanting, has been much less successful. Juniper litter appears to provide an undesirable seedbed for seeded species and annual grasses tend to occupy areas with litter. Ramsey (1989*) provides some evidence that leachates from juniper slash, one year old red slash more so than green slash, can inhibit growth of perennial grasses.

Research conducted in central Oregon (Washington and Eddleman 1995, unpublished data) on western juniper woodlands that have depauperate understory vegetation, often dominated by annual grasses, provides evidence that perennial grasses (squirreltail, bluebunch wheatgrass, big bluegrass, thickspike wheatgrass, and western wheatgrass) can establish in these woodlands. On one site where squirreltail and bluebunch wheatgrass were utilized, establishment and seed production of these species was greater where (1) western juniper was cut compared with no cutting, (2) with transplants compared with direct seeding, and (3) where medusahead (if present) was burned before transplanting or direct seeding compared with no burning. Establishment from direct seeding within medusahead was poor unless medusahead was burned previous to seeding. Western juniper slash, scattered after cutting, enhanced seed production of squirreltail and bluebunch wheatgrass compared with no slash, while on another site, western juniper slash, again scattered after cutting, generally enhanced establishment of all 5 species mentioned above compared with no slash. The benefits of slash were related to the amount of slash utilized, appearing to be maximal at 50% ground cover, with somewhat reduced establishment below and above this amount. There also appeared to be an interaction between amount of slash utilized and the precipitation received, with less slash being required in wet years. Establishment rates for direct seeding, although less than for transplants, were judged to be high enough to discourage the extra effort associated with transplanting. Establishment itself is encouraging, but Washington and Eddleman (1995) caution that lateral spread of these grasses, which is the next positive step, has yet to be ascertained.

Without any planting of perennial species, residual perennial grasses increased in density and seed production after cutting of these western juniper woodlands. Cover of perennial grasses increased, but so did the cover of the annual grasses. Perennial forbs and half-shrubs increased in abundance also, and several species were observed that were not observed previous to cutting. In total, these responses were less evident on the medusahead-dominated sites however. Eventual site dominance by perennial species is the goal, but Washington and Eddleman (pers. comm. 1995) propose that this goal might be unattainable in the short or long-term, on sites dominated by annual grasses, and their efforts are structured to achieve a more realistic objective of just "getting native species back into the system." On sites without a sizeable population of residual native plants, Washington and Eddleman (1995) propose that planting is required to establish desirable species. The grazing management guidelines listed below for "woodlands receiving western juniper control" should be followed to sustain these native species.

g. Commercial Harvest on Private Land

Western juniper woodlands represent a supply of timber which has recently become a focal point stimulating interest in commercial harvesting on private land, especially with the general decline of timber supply and shutdown of mills in the Pacific Northwest (Swan 1995). Western juniper represents the least utilized wood fiber resource in the region (Swan 1995). To explore the possibility of utilizing this resource, an ad hoc commercialization "Steering Committee" was formed by various interests after a "Juniper Forum" in 1993. The mission of this group is to ". . . encourage awareness and development of an integrated western juniper industry, in a manner which will ensure long-term sustainability of the resource, benefit landowners and local communities, and stress value-added processing and full utilization of available material." Membership includes representatives from the wood products industry, government/non-profit organizations, and private landowners, and meetings are held about twice per year (Swan 1995).

Future commercial harvest of western juniper on private lands will probably take place on sites where western juniper grows near or within the peripheral boundary of ponderosa pine-mountain big sagebrush communities. The reasons for this are (1) higher volumes per acre, (2) better access to stands and markets, and (3) possibility of combining western juniper harvest with other commercial harvest operations. Counties in Oregon with substantial stands of juniper meeting these conditions are Klamath, Lake, Deschutes, Crook, and Wheeler (Gedney 1993, in Haugen 1993, Swan, pers. comm. 1995).

The ecological ramifications of future commercial harvest encompass wildlife habitat, biodiversity, nutrient cycling, hydrological function, and forage production for livestock and wildlife. These ramifications are largely speculative at present. Large-scale removal operations will affect species that exist in or utilize western juniper woodlands (see Table 2) as well as those that exist in or utilize lower (that is, less vertical) structured communities such as shrub-steppe or grassland. There is a high potential for increased forage production after western juniper removal that could be utilized by livestock. This potential is driving the interest of private landowners in commercial harvest to some extent. Whole-tree harvest, which apparently is favored by commercial harvest industry representatives (Swan, pers. comm. 1995), has potential negative ramifications for nutrient cycling, especially on inherently nutrient-deficient sites (see Site Nutrients above). Bole removal, with slash distribution across the site, would lessen nutrient "mining" and potentially be less deleterious to site productivity, and more beneficial to native plant species recovery. This strategy would permit infiltration also and prevent excessive runoff and sediment transport (erosion) off-site (see page 28). Given present knowledge, the bole removal + slash distribution strategy is recommended over whole tree removal for commercial harvest operations on federal lands, if and when these operations are implemented. Grazing management guidelines listed for "woodlands after receiving western juniper control" (see below) are recommended.

Grazing Management

Guidelines for grazing management in western juniper woodlands should have as their foundation interrelated goals that are associated with watershed health and vegetation health. In regards to watershed health, grazing management should seek to

(1) permit sites to capture water, that is, maintain high infiltration rates and high capacity surface detention storage,

(2) permit effective water storage, through maintenance of soil organic matter and well dispersed litter and plant canopies that reduce evaporation losses from the soil, and

(3) permit release of water from the site as subsurface flow, runoff with low sediment load, and plant use. In this scenario, potential use of water in plant physiological processes is promoted and evaporation at the soil surface is restricted.

In regards to vegetation health, grazing management should seek to

(1) permit plants to capture resources sufficient for growth and survival. This would include maintenance of a photosynthetically active leaf area and active root system,

(2) permit plants to store resources that are necessary for drought survival, overwintering, and new growth initiation, and

(3) permit plants to retain canopy cover and litter sufficient for protection from mortality or loss of vigor during stress periods. Canopy cover promotes resource accumulation and storage and litter promotes soil water retention and thus root growth and resource storage.

Grazing management, per se, in western juniper woodlands has not been addressed by researchers. However, biological, physiological, and ecological research that has been conducted in woodlands, combined with research on plant response to herbivory, can be utilized to present the best information available on grazing management. Grazing management should be evaluated in 3 different resource situations, including existing woodlands, woodlands that have received juniper control, and sites that are susceptible to western juniper expansion. The goals above are applicable to all 3 situations.

The guidelines suggested below are intended only to satisfy the goals established above and objectives that might be developed from these goals. These guidelines should be adjusted for changing conditions of vegetation and soil as well as kinds of use. The guidelines are conservative and represent a worse-case scenario in some cases, that is, a stand of western juniper trees with high (for the site) canopy cover and a meager understory. The amount of grazing use can be increased from that suggested below if the following exists (1) an open woodland, (2) a good condition understory vegetation, or (3) a moist site with relatively high precipitation. The amount of grazing use might also be increased if grazing management strategies are judiciously adapted to the ecological site, to variables of overstory-understory conditions, and to seasonal and annual variations in precipitation.

a. Young, High (For the Site) Canopy Cover Woodlands, on Shallow Soil

Objectives

1) High vigor desired forage plants
2) Understory plant canopy cover
3) Well dispersed plants across site
4) High litter cover and dispersion

Guidelines to Satisfy Objectives

1) Light utilization as plants near maturity, or light utilization after maturity
2) Repeated light use during late growth period only in years receiving regular effective precipitation inputs during the effective growth period. Here and elsewhere where this guideline is written, caution is required because we do not know yet what effective precipitation inputs are in relation to timing and interval, at the species level in western juniper woodlands.
3) Utilization not exceeding 15 to 25%, to permit retention of horizontal extent (cover) of plants.

Rationale

Where dry conditions or shallow soils (generally less than 30 cm deep) exist, soil storage of precipitation is low and soil water available for understory growth becomes limiting in amount and duration. Characteristics of western juniper that exacerbate the potential for understory growth include (1) the interception of precipitation by the canopy and litter layer, (2) the use of stored soil water from the intercanopy areas before understory species commence growth and during growth periods of understory species, and (3) the use of incident precipitation that falls during summer dormancy of understory species. Grazing of forage species during the growth period under the above conditions is hazardous because plant loss of vigor, density, and ground cover is likely. Effective precipitation for growth is restricted mainly to fall, winter, and spring, thus the window of water and nutrient availability is optimal only early or late in the growing season and it is short. Grazing during the early portion of the growing season would appear to be damaging to understory plant vigor because the short window of soil water and nutrient availability might close and prevent regrowth. Fall precipitation might permit regrowth and permit light grazing of 10 to 15% utilization of forage plants that are reaching maturity.

The deleterious effects of moderate to heavy grazing of understory species will probably not be ameliorated by rest of 1, 2, or even 3 years because during the grazed periods, western juniper will incrementally gain in site dominance and impede future recovery of understory species during ungrazed periods. The importance of rest in permitting recovery will increase if rest is concurrent with wet years.

Grazing of plants after maturity has effects on the insulating qualities of the plants relative to the soil, which in turn has hydrological effects to the site. Understory plants insulate the soil from soil temperature fluctuations and moisture evaporation. Understory plants lose their insulating effectiveness if they sustain heavy grazing and do not regrow before winter. Wet soil surfaces in intercanopy areas of juniper woodlands, characterized by a lack of plant or snow insulation, can develop concrete frost in the cold portion of winter and subsequently freeze and thaw diurnally in late winter and early spring. Precipitation can run off of soils with concrete frost because infiltrability is nearly zero. Freeze-thaw activity pulls water to the soil surface where it can evaporate. Temporary warm winter periods in western juniper woodlands, when coinciding with unfrozen soil, can result in evaporation of surface soil moisture.

Precipitation events typically are not of sufficient amount to fully recharge the soil and counteract the evaporative loss in western juniper woodlands that have sustained grazing in the late growing season. Soil water storage and available water for plant growth the next growing season can be reduced on shallow soils with inherent low water storage capacity.

Conversely, some shallow soils, particularly those associated with low sagebrush, can become saturated during the winter. Added inputs of precipitation or snow melt on these saturated shallow soils can result in runoff. Plant cover and dispersion, and litter, can reduce sediment transport in this runoff.

b. Young Woodlands on Deep Soil

Objectives

1) High vigor desired forage plants
2) Understory plant canopy cover
3) Well dispersed plants across site
4) High litter cover and dispersion
5) Sustained growth of desired plants during growing season

Guidelines to Satisfy Objectives

On sites characterized by prevalent forage grasses

(1) Light utilization as plants near maturity, or light utilization after maturity, and
(2) Repeated light use during late growth period only in years receiving regular effective precipitation inputs during the effective growth period.

On sites characterized by a declining grass base, light utilization and substantial periods of rest.

On sites characterized by virtually no vascular plant cover, non-use.

On sites characterized by full occupancy by annual grasses such as cheatgrass or medusahead, carefully planned grazing or non-use.

Rationale

Potentially greater amounts of available soil water can be stored in a deep soil compared with a shallow soil. This translates to greater potential biomass production of understory species and greater potential for regrowth and plant recovery from grazing. Healthy understory plants with canopy cover promote detention of surface water, absence of concrete frost, and dispersion of plant biomass over the site, as mentioned previously. Grazing utilization after plant maturity should not be heavy as this restricts maintenance of the above conditions and thus, water storage during the winter.

Water storage during the winter, supplemented with additional precipitation in the spring, can sustain plant growth over relatively long durations. Successive light removal of herbage with grazing should be possible during this growing period under these conditions and not adversely affect either plant vigor or the nutrient pool of the plant. Bitterbrush, other shrubs, and forbs would not likely be utilized excessively under this guideline and competition of annual grasses with perennial grasses would not likely be increased. The probability of interference of western juniper with understory species is increased if grazing results in utilization that delays plant regrowth initiation. This situation should be avoided.

Sites that support a declining grass base will probably require light use and extended rest periods to permit plant recovery. Sites that support virtually no vascular plant cover cannot legitimately accommodate any grazing prescription except non-use. There should be little expectation for understory species recovery even in the absence of grazing. Full site occupancy by annual grasses such as cheatgrass or medusahead mandates carefully planned grazing or non-use because grazing utilization of these species can result in sediment loss from the site during periods of potentially high runoff.

c. Woodlands after Receiving Western Juniper Control

Objectives

1) Rapid site dominance by desired understory species
2) High vigor desired forage plants
3) Understory plant canopy cover
4) Well dispersed plants across site
5) High litter cover and dispersion
6) Sustained growth of desired plants during growing season

Guidelines to Satisfy Objectives

Sites that support prevalent understory vegetation at the time of control

(1) Non-use in year 1 post-treatment; defer grazing until seed set in year 2, and

(2) Repeated light use, rest, rotated seasonal use, and deferred use are possible grazing strategies that might satisfy plant vigor and watershed health goals and objectives.

Sites that support moderate understory vegetation at the time of control

(1) Non-use in year 1 and 2 post-treatment; defer grazing until seed set in year 3, and

(2) Repeated light use, rest, rotated seasonal use, and deferred use are possible grazing strategies that might satisfy plant vigor and watershed health goals and objectives.

Sites that support little if any understory vegetation at the time of control

(1) Non-use until year 3 or 4 post-treatment, when recovery of plant vigor is apparent, including reproduction and seedling establishment,

(2) Single or repeated light use when plants are nearing maturity, or light use after maturity, possibly until year 5 or 6 post-treatment, until the site satisfies the planned vegetation and watershed objectives, and

(3) Repeated light use, rest, rotated seasonal use, and deferred use are possible grazing strategies that might satisfy plant vigor and watershed health goals and objectives.

Sites that are seeded

(1) Non-use until year 2, 3, or 4 post-treatment, when seedling establishment is attained and a competitive population is present,

(2) Single or repeated light use when plants are nearing maturity, or light use after maturity, possibly until year 4, 5 or 6 post-treatment, until the site satisfies the planned vegetation and watershed objectives, and

(3) Repeated light use, rest, rotated seasonal use, and deferred use are possible grazing strategies that might satisfy plant vigor and watershed health goals and objectives.

Adjustments in these guidelines might be necessary because control might be accomplished by several different harvest techniques or fire, all of which affect site responses to grazing management somewhat differently. Grazing guidelines must be adjusted to foster certain species compositions over others, in addition to plant vigor and productivity. For example, the pursuit of these grazing management guidelines should be avoided if they result in a rapid buildup or dominance of undesired species, such as cheatgrass, medusahead, or noxious weeds.

Control of western juniper does not result in permanent conversion on these sites. Seedlings will undoubtedly be present on uneven-aged stands that sustain juniper removal, and a sizeable seed bank of western juniper will undoubtedly exist on even-aged or uneven-aged stands that sustain juniper removal. These mechanisms ensure future site dominance by western juniper. Follow-up management that might include burning, or periodic entry for commercial harvest (not practiced currently on federal land) will be required to maintain non-woodland or open woodland conditions.

Rationale

Understory species typically respond positively in production after removal of western juniper. Herbaceous production on a species-specific level typically peaks at year 2 or 3 post-removal of western juniper. Subsequent herbaceous production typically declines to a level somewhat higher than the pre western juniper treatment level. Recovery time might be delayed on sites that support moderate to little or no understory vegetation because species might need to establish new populations from newly formed seed banks or other propagules.

The probability and amount of regrowth are increased on these sites. This is attributable to enhanced soil water availability subsequent to the removal of western juniper, which extends the length of the growth period. Observations indicate continuous spring, summer, and fall understory growth in year 1 and 2 post-removal of western juniper. Preferable grazing intensities should be at a level such that some photosynthetic tissue remains after grazing from which regrowth can initiate, rather than total denudation of plants and regrowth being initiated through new tiller and leaf material.

d. Sites Susceptible to Western Juniper Encroachment and Dominance

Objectives

1) Maintain site dominance by desired understory species
2) High vigor desired forage plants
3) Understory plant canopy cover
4) Well dispersed plants across site
5) High litter cover and dispersion
6) Sustained growth of desired plants during growing season
7) Prevent rapid dispersal of western juniper seed originating from upslope, accomplished through previous 6 objectives
8) Limit big sagebrush density

Guidelines to Satisfy Objectives

Numerous guidelines already presented in the preceding sections are applicable here, depending on soil depth of the sites, and visual trend and composition (for example, stable trend, declining trend, dominance by annual grasses, hardly any herbaceous biomass, etc.) of the herbaceous species. Sagebrush control, especially by burning, is an option to reduce sagebrush densities.

Rationale

Maintenance of a vigorous grass cover will restrict surface flow of water during the late fall, winter, and early spring periods, which are typical seed dispersal periods for western juniper. Western juniper seed dispersal will be restricted if a vigorous grass cover is present that promotes good surface water detention, combined with nonextensive patches of bare soil where concrete frost can form.

As mentioned previously, big sagebrush provides a safe site for establishment of western juniper seedlings. Sagebrush control measures might be necessary on some sites to reduce sagebrush densities to a reasonable level. The maintenance of a vigorous understory will restrict establishment of sagebrush and western juniper seedlings.

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(NOTE TO SENIOR AUTHOR: NEED TO PUT IN THE ASTERISKED CITATIONS YET, FROM EDDLEMAN ET AL. 1994).