Western Juniper Woodlands

(of the Pacific Northwest)

Science Assessment

October 6, 1994

Lee E. Eddleman
Professor, Rangeland Resources
Oregon State University
Corvallis, Oregon

Patricia M. Miller
Assistant Professor Courtesy
Rangeland Resources
Oregon State University
Corvallis, Oregon

Richard F. Miller
Professor, Rangeland Resources
Eastern Oregon Agricultural
Research Center
Burns, Oregon

Patricia L. Dysart
Graduate Research Assistant
Rangeland Resources
Oregon State University
Corvallis, Oregon

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

Page

LIST OF TABLES

LIST OF TABLES (Cont'd.)

SCIENCE ASSESSMENT

EXECUTIVE SUMMARY

WESTERN JUNIPER (*Juniperus occidentalis* Hook. ssp. *occidentalis*) WOODLANDS

Distribution of Western Juniper (*Juniperus occidentalis* ssp. *occidentalis*) woodlands is across a broad variety of vegetation types, soils, landscapes and moisture regimes. Area occupied by western juniper woodlands in the Pacific Northwest is nearly 4 million acres (about 1.6 million ha). Over 2.3 million acres of woodland are in Oregon with approximately 10% of the area in old woodlands. Nearly 90% of the area in Oregon is composed of young woodlands with trees less than 150 years old. Data and observation indicate the species continues to expand its range into new areas.

Prehistoric Expansion and retraction of western juniper took place over long time periods. Data indicate that where it did occur, its density was less than that at present.

Historic Expansion of western juniper woodlands has originated from open, sparse and savannah-like stands of old juniper trees many of which are today 400 to 600 years of age or even older. Many of these stands were growing on topographic situations where fire would have been restricted. Factors which may have influenced the rapid expansion were a combination of mild winters with greater precipitation, reduced fire frequency and livestock grazing that contributed to increases in big sagebrush reduced production of grasses. Development of present day woodlands occurred under a different combination of variables than prehistoric expansion, therefore present day woodland communities have different plant composition and structure than prehistoric woodland plant communities.

Biological attributes of western juniper that play a significant role in expansion, competition and dominance are numerous. Big sagebrush plants are implicated as major contributors of safe germination and establishment sites and as locations for successful completion of the juvenile phase of growth for western juniper. Growth is usually very slow the first few years. Young juniper begin to overtop big sagebrush plants when they are about 20 to 30 years old. Trees, eight to nine decades old, may grow six to seven inches (15-18 cm)/year in height. A strong lateral root system is developed at an early age and some of these lateral roots or even a taproot may penetrate very deeply into soil and rock cracks.

Height and diameter growth rates of western juniper trees beyond 35 years of age have not been studied. General observation indicates a variation in growth rate depending on topographic position, soil type and woodland tree density.

Trees begin to produce abundant seed crops at 60 to 75 years of age. Seed vectors include a variety of birds and other animals, gravity and water. As stands of western juniper mature they commonly reach a canopy cover of 20% to 30% and densities of 40 to 100 trees/ac (about 100 to 240/ha). Within Oregon there is about 0.28 million acres(114,000 ha) of western juniper woodlands with an average canopy cover of 45%. Tree densities frequently exceed 400/ac (1,000/ha) and densities in excess of 4,000/ac (10,000 ha) have been recorded.

The primary mortality factor affecting western juniper was fire. However stand conditions with little understory fuel to carry a fire, fire risk factors, and policies which contribute to fire control have limited the influence of fire as a mortality factor. Insects and diseases as agents of juniper mortality are poorly studied. Observation indicates that individual trees and small groups of trees have been killed by these agents.

Physiological studies of western juniper show an age related trend toward increasing allocation of energy to construction of aboveground tissues. Adult foliage reaches a nitrogen content of about 1.2%. Carbon dioxide (CO_2) assimilation per gram of foliage tissue appears to decline with age from a peak value of 587 μmol/g/day in juvenile foliage to a peak of 324 μmol/g/day for adult foliage.

Models are available for estimating juniper aboveground biomass, leaf biomass and leaf area from a variety of measured parameters including basal circumference. Both CO_2 assimilation and transpired water loss have been measured for juvenile and adult foliage and these measurements can then be projected to trees of various size classes. For example, for the estimated total daily CO_2 assimilated and total daily water transpired an adult western juniper tree 33 feet (10 m) in height with a basal diameter of 18 inches (46 cm) and a basal circumference of 57 inches (145 cm) ranged from a high in August of 661 grams of CO_2 assimilated and 137 liters (36 gal) of water transpired into the atmosphere to a low in November of 10 grams of CO_2 assimilated and 5 liters (1.3 gal) of water transpired.

A model is available for assessment of water use by developing stands of western juniper based on stand density, basal area, temperature, radiation and precipitation.

Physiological information is rather extensive for western juniper but almost no data is available for other associated plant species associated with western juniper woodlands with the exception of a few species that have been studied in plant communities outside the woodland.

Ecological studies of western juniper woodlands are incomplete in many respects. Woodlands exist on a variety of soils derived from a wide range of parent materials. However, studies correlating soil conditions to western juniper populations and production and to associated plant community structure and function are limited. Spatial distribution patterns of soil nutrients develop in the presence of western juniper. This pattern tends toward greater patchiness with tree age.

Successional changes in understory vegetation associated with increasing western juniper dominance are not sufficiently documented. Spatial measurements and general observations indicate that certain shrub and forb species present in communities without juniper are absent or appear as dead individuals on similar ecological sites where closing young woodlands of juniper exist. Plant species numbers, density and production, other than juniper, appear to decline and patterns of plant distribution change as trees grow and woodlands develop over time. Many young woodlands are in successional transition between states, therefore future plant communities are largely unknown for the many ecological site on which they exist.

Fire is an effective control agent of western juniper to prevent expansion into associated plant communities, to reduce stand densities, and to create a mosaic of plant communities on a landscape. Both grasses and shrubs, particularly sagebrush, are needed to supply sufficient fire fuel to cause death in larger individual trees therefore fires may not carry in a well developed woodland where these fuels are in low supply.

Grazing studies on western juniper woodlands are absent from the literature, however observations and data from other types of juniper woodlands indicate a heightened sensitivity of understory plants to herbivory. The effects of tree competition and herbivory have not been generally separated.

Microbiotic crust structure and function have not been studied in western juniper woodlands. Studies from southwestern pinyon-juniper woodlands showed that cover of crusts under certain kinds of grazing was reduced but that species numbers could respond either positively or negatively to grazing activity. Tree spacing and forb and grass cover may influence crusts at the species level. Both tree canopy cover as well woody and needle debris may reduce crust cover.

Hydrologic processes in western juniper woodlands are influenced by tree canopy and from the litter layer. Canopy interception losses may exceed 12% of the annual precipitation. Water runoff and sediment loss are influenced by canopy cover of all plants, plant density and spatial distribution of plants. Water and sediment loss in overland flow appears to be very high for some juniper sites. However runoff as a function of the interaction of soils, plants and climatic events at the site level have been studied insufficiently to develop acceptable standards. Extrapolation of hydrologic data from small-plots to watershed level predictions is risky. Data for the fall, winter and early spring, a period that is hydrologically active, are not available.

Wildlife use and impact of management activities in western juniper woodlands are poorly documented and little researched. Key unresolved questions relative to wildlife-western juniper habitat interactions are; what is the level of importance of the woodlands, what structural components of woodlands are important. What landscape level vegetation patterns are important, what will be the effect of successional changes in these woodlands since they are in transition to different communities. Management guidelines for species using western juniper woodlands has largely been derived from observation and information gleaned from other vegetation types. Exceptions are mule deer and bird species such as Townsend's solitaire where a reasonably good data base exists.

Conversion of western juniper woodlands to other vegetation types by killing juniper usually leads to an immediate and large increase in production of understory vegetation and an increase in numbers of plant species. The aboveground portion of the juniper tree contains a significant amount of nutrients such that on nutrient poor sites the retention of foliage and branches might be necessary. Guidelines as to critical threshold densities of understory plants, standards for watershed health, restoration of native species, methodologies for revegetating seriously degraded sites and improving understory vegetation in the presence of juniper trees remain to be developed.

Grazing Management of western juniper woodlands may result in range improvement, if proper, or range degradation if improper. Within western juniper woodlands the trees on many sites prove to be an overwhelmingly dominate in terms of interference or competition for water, nutrient and light resources. Understory vegetation may prove to be sensitive to grazing during certain seasons and utilization levels. Proper grazing management needs to be flexible and adaptive in accounting for variables of ecological site, season and year. Overgrazing may lead to a rapid and potentially irreversible decline in understory plant resources.

October 6, 1994

SCIENCE ASSESSMENT

WESTERN JUNIPER (*Juniperus occidentalis* Hook. ssp. *occidentalis*) WOODLANDS

Introduction

Juniperus occidentalis Hook.[1] has been separated into two subspecies by Vasek (1966); *J. o*. ssp. *australis*, usually referred to as Sierra juniper; and *J. o.* ssp. *occidentalis,* usually referred to as western juniper. Sierra juniper occupies the southern portion of the range, primarily along the Sierra Mountains of California while western juniper occupies the northern portion of the range which includes northern California and northwestern Nevada across Oregon east of the Cascade Mountains into southwestern Idaho. A few scattered stands also occur in southeastern Washington.

Western juniper; the northern subspecies and the subject of this assessment; is widespread, occupies a broad variety of habitats, and in the recent past began a significant expansion of its range into what had been assumed to be stable plant communities. As community dominance shifts toward young woodlands of western juniper, other structural elements are likely to adjust. Increases in cover of pinyon pine and juniper in other areas are reported to cause major declines in shrubs (West 1984, Arnold 1964) and declines in the herbaceous component (Arnold et al. 1964, Tausch 1980, Clary 1971, and Clary and Jameson 1981). Such changes impact plant and animal habitats as well as water, nutrient and energy flow in these ecosystems. Old western juniper woodlands with their old trees may be unique and deserve consideration, but are poorly studied as units with regard to whole ecosystem properties.

In many respects what is known about western juniper woodlands is much less than what needs to be known for management purposes. However, integration of those studies that have been completed in western juniper with those in the associated pinyon-juniper woodlands and with basic principles of ecosystem operation allow the development of a fairly good picture of the western juniper woodland system.

Weaknesses in and absence of information exist in some areas of woodland ecosystem function and process. However there are several studies that have just been completed or are in progress which when published will broaden our understanding.

---

[1] Unless otherwise specified nomenclature follows that of Hitchcock, C.L., A. Cronquist, M. Dovenby, and J.W. Thompson. 1955, 1959, 1961, 1964, 1969. Vascular Plants of the Pacific Northwest. Parts 1-5, University of Washington Press.

Current Status

Distribution of Western Juniper

Vasek (1966) classified western juniper (*Juniperus occidentalis* Hook.) into two subspecies *occidentalis* from Susanville, Lassen County California northward and *australis*, from Lassen County southward. As stated above, this assessment will focus only on the northern *J. o.* ssp. *occidentalis* and discussions of western juniper and western juniper woodlands will deal with the race of the northern woodlands. Vasek cites the *occidentalis* type specimen as having been collected on the banks of the Columbia river in 1826.

Western juniper occupies an area extending from Lassen County California northward across Oregon to the Columbia River and from just east of the Cascade Mountains to the Owyhee Plateau of southeastern Idaho. Scattered stands occur in southeastern Washington and in northwestern Nevada. The species is sparse in northeastern Oregon and is widely scattered in southeastern Oregon. West of the Cascades it extends from Trinity County California into southern Jackson County Oregon (Vasek 1966 and Dealy 1990).

Sowder and Mowat (1958) give variable elevational ranges for western juniper depending on location. Along the Columbia River its elevational range is from 183 to 549 m (600 - 1,800 ft). In central Oregon it is most abundant on plateaus at 915 to 1,220 m (3,000 to 4,000 ft). Driscoll's (1964a) central Oregon island study was at 732 m (2,400 ft) while Rose (1989) conducted his central Oregon study at about 1,340 m (4,400 ft). In northeastern California it is abundant at 1,220 to 1,524 m (4,000 to 5,000 ft). Dealy et al. (1978b) gives an upper elevational range of 1,982 m (6,500 ft). Western junipers elevational range on Steens Mountain in southeastern Oregon is from 1,450 to 2,000 m (4,756 to 6,560 ft) (Miller and Rose 1995).

Several general estimates have been made as to the areal extent of western juniper. The following values are given in the literature and include various densities with values rounded to thousands:
-- 1936 - 540,00 ha (1,335,000 ac) grid measurement of USDA For. Serv. 1936, 1937 Forest Type Map of Oregon; includes western juniper of any size class and density.
-- 1964 - 880,000 ha (2,174,000 ac) for Oregon (from a planimetering of Kuchler's 1964 regional distribution map - cited in West et al. 1975).
-- 1969 - 162,000 ha (400,000 ac) for southwestern Idaho (data source not given, Burkhardt and Tisdale 1969).
-- 1972 - 53,000 ha (132,000 ac) for Oregon National Forest Lands, 662,000 ha (1,635,000 ac) for Oregon federal non-National Forest lands (1970 resource base, USDA For. Ser. Forest-Range Task Force 1972). No area was given for non-federal lands. No values were given for Washington and although area is given for California, Idaho and Nevada values are a composite including other

Juniperus spp. and pinyon pines (*Pinus* spp) and western juniper cannot be singled out.

-- 1978 - 1,146,000 ha (2,832,000 ac) for north central through south central Oregon (Dealy et al. 1978a).

-- 1989 - 520,000 ha (1,284,000 ac) in California (mostly *occidentalis)* of Shasta, Lassen, Modoc and Siskiyou Counties but includes some area for *australis* (surveys - Bolsinger 1989).

-- 1990 - 879,000 ha (2,172,000 ac) in eastern Oregon, exclusive of National Forest land (surveys - Oswald 1990).

These estimates suggest that there is in excess of 932,000 ha (2,303,000 ac) of western juniper woodland in Oregon and a total of approximately 1,614,000 ha (3,988,000 ac) in Washington, Oregon, Idaho, California and Nevada.

Old western juniper woodlands, those with old trees and mixed population structure, and young western juniper woodlands, those with trees less than 150 years old are not easily separated in the literature as to aerial extent. Data for Oregon by Oswald (1990) indicates about 81,000 ha (200,000 ac) of woodland over 100 years old and 798,000 ha (1,970,000 ac) in woodland less than 100 years old or nearly a 10-fold increase. It should be noted that Oswald's data do not include woodlands developing from populations arising in the last 35 years.

In this assessment the authors have arbitrarily placed western juniper into two age-related groups: (1) young woodlands — those containing trees less than 150 years old, and (2) old woodlands — those containing trees generally 200 to 400 years old or older. The section on woodland maturity (page 47) provides further discussion on these two groups.

Holocene Changes in Western Juniper Woodlands

Introduction

Climate change during the late Pleistocene and Holocene caused major changes in vegetation distribution throughout the Intermountain Region of the western United States (Wells 1983, Nowak et al. 1994). These climatic changes have caused large changes in the distribution and structure of western juniper woodlands during the past 30,000 years (Thompson et al. 1986, Mehringer and Wigand 1990, Miller and Wigand 1994).

Prehistoric Expansion of Juniper

Climate during the Pleistocene was generally colder and wetter than in the Holocene (the last 12,000 years) (Davis 1982). During the Holocene, climate has fluctuated with periods of cooler/wetter, cooler/drier, warmer/drier and warmer/wetter weather patterns than at present (Antevs 1938, Davis 1982). There is also evidence that season of maximum precipitation has varied across the Intermountain Sagebrush Region (Davis 1982, Wigand and Nowak 1992). Within the Intermountain West, fluctuations in lake levels and salinity, glacial advances and retreats, regionally correlated tree ring widths, and changing animal assemblages strongly indicate changes in climate (Grayson 1993). In addition, changes in plant community composition inferred from pollen data and plant macrofossils recovered from ancient packrat middens, dry caves, sediments from lake, fen and marsh, and Native American archaeological sites have been used as evidence indicating climatic variation.

Prostrate juniper (*Juniperus horizontalis*) and common juniper (*J. communis*) were growing in southeastern Oregon during portions of the late Pleistocene (Wells 1983). Packrat middens suggest the more drought tolerant juniper species, which comprise the semi-arid woodlands of today in the Intermountain West, were distributed 500 to 640 km farther south, and 1,000 to 1,500 meters lower in elevation during peak glaciation than their current range (Wells 1983, Thompson 1990, Wigand and Nowak 1992). Other packrat midden data indicate western juniper (probably the southern variety, var. *australis*) was growing in Kings Canyon, California during maximum glaciation (Cole 1983). Western juniper (probably the northern variety, var. *occidentalis*) appears in the fossil midden record on the east shore of Lake Lahontan in Nevada about 12,000 years ago (the more mesic side receiving the benefit of lake effect) (Thompson et al. 1986). At the same time, Utah juniper characterized the woodlands of the drier rain shadow affected western shores of Lake Lahontan (Wigand and Nowak 1992). The earliest evidence of western juniper reported within its historic range of northeastern California and eastern Oregon occurs between 4,000 and 7,000 years ago. This is indicated from charcoal sediments immediately beneath Mazama ash in Fort Rock Cave, Oregon (6,700 years ago) (Bedwell 1973); seeds and twiglets from ancient woodrat middens at Lava Beds, California (5,400 years ago); and Diamond Craters, Oregon (4,000 years ago) (Mehringer and Wigand 1987). Evidence from pollen records indicates that western juniper (based upon inference from the packrat midden record) has been in those areas at least since the middle Holocene, although it may have arrived during the early Holocene.

Following the Hypsithermal (warmer and/or drier) interval some 4,500 years ago plant pollen and macrofossil data indicate gradually increasing winter and summer precipitation, punctuated by dramatic but brief increases in moisture (Antevs 1938, Davis 1982, Wigand 1987). From 4,000 to 2,000 years ago, conditions were significantly wetter than present (Davis 1982, Wigand 1987). Temperatures cooled and winter precipitation increased dramatically in comparison to summer precipitation. Juniper pollen values began to rise about 4,500 years ago and increased dramatically in the Diamond Pond area of southeastern Oregon in the northwestern Great Basin 4,000 years ago and remained high (with intermittent drops until about 1900 years ago (Wigand 1987, Mehringer and Wigand 1990). The downslope expansion of the lower juniper tree line, by as much as 150 m (492 ft) in elevation, is confirmed by western juniper macrofossils from packrat middens at Diamond Craters in southeastern Oregon (Mehringer and Wigand 1990), and Lava Beds National Monument in northcentral California (Mehringer and Wigand 1987).

Juniper pollen values during the Neoglacial Period above 2,200 m (7,218 ft) at Fish Lake on Steens Mountain in southeastern Oregon remained lower than those presently found in Fish Lake (Mehringer and Wigand 1987). This suggests that during prehistoric juniper woodland maximum extent, the upper tree line lay below that of today. Severe winter conditions at the higher elevations probably restricted upslope expansion of juniper (Mehringer 1987). However, juniper did seem to expand slightly upslope at the end of the middle Holocene when conditions were much warmer, as well as increasingly wetter (Mehringer and Wigand 1987).

During Neoglacial expansion, abundance of juniper pollen on Steens Mountain remained less than pollen abundance during the second half of the 20th-century (Wigand 1987). This indicates twentieth-century woodlands are more dense than woodlands of the past (Miller and Wigand 1994). Abundant grass pollen during prehistoric expansion also indicates a vigorous herbaceous understory. Although climatic conditions at the lower elevations were good for juniper growth and establishment, frequent fires fueled by abundant herbaceous understory vegetation (indicated by an increase in both charcoal and grass pollen at both Diamond Pond and Fish Lake; Mehringer and Wigand 1987) probably helped maintain the open tree stands.

Since the end of the Neoglacial 1,900 years ago, climate has became generally warmer and drier across the Great Basin (Davis 1982, Wigand 1987, Wigand and Nowak 1992). The plant macrofossil record from Diamond Pond indicates the decline in regional water tables (Wigand 1987). Dramatically declining juniper pollen and packrat midden data at the western base of Steens Mountain reflect the upslope retreat of the western juniper woodland (Mehringer and Wigand 1990, Wigand 1987). Reduced juniper pollen values, with respect to grass and reduced coarse to fine charcoal ratios, indicate a shift to more arid steppe (Miller and Wigand 1994). Coarser charcoal reflect juniper fuels and finer charcoal indicate shrub and herbaceous fuels. Following the Neoglacial interval, increased sagebrush pollen relative to grass pollen at the higher elevations on Steens Mountain reflects a more xeric, less grass dominated sagebrush steppe (Mehringer and Wigand 1987). Expansion of salt deserts at the expense of shrinking marshes, evidenced by greater chenopod pollen values at Diamond Pond, indicate a period of increasing aridity, particularly between 1,900 and 1,000 years ago (Wigand 1987).

Around 1,000 years ago, the occurrence of juniper pollen at Diamond Pond and western juniper macrofossils in the packrat middens on Diamond Craters and Hart Mountain in southcentral Oregon began to increase (Wigand 1987). However, 700 and 500 years ago, a period characterized by several major fire and drought events, western juniper pollen values dramatically decreased in southeastern Oregon (Wigand 1987). Beginning 400 to 500 years ago, a pattern of stronger winter precipitation developed, initiating a gradual re-expansion of juniper woodland in the northern Great Basin (Mehringer and Wigand 1990). Juniper pollen values during the Holocene in the Fish Lake record suggests that western juniper woodland may have been expanding at higher elevations during this period (Mehringer and Wigand 1987). It also appears western juniper was again gradually expanding, just prior to settlement (Mehringer and Wigand 1987).

Historic Expansion of Juniper

Abundance of juniper pollen in southeastern Oregon has gradually increased since 1500 A.D., fluctuating in the early 1800s, and sharply increasing in the mid 1900s (Mehringer 1987). Since culmination of the Little Ice Age in the mid 1800s, temperatures have been rising (Ghil and Vautgard 1991). Rising temperatures have been accompanied by an increase in sagebrush pollen relative to grass pollen, and a decrease in the water table at Diamond Pond near Steens Mountain in eastern Oregon (Wigand 1987).

Relict juniper woodlands, tree-age class ratios, and historical documents generally indicate western juniper woodlands prior to Euro-American settlement were open, sparse, and savannah-like (Burkhardt and Tisdale 1969, Vasek and Thorne 1977, Miller and Rose 1995, EOARC data files). In southeast Oregon and northeast California, where soils are primarily derived from igneous material, the majority of old trees (ranging up to 600 years) are located on the shallow soil low sagebrush flats and rocky ridges where fine fuels were too low in abundance to carry a fire (Vasek and Thorne 1977, EOARC data file). Densities of presettlement trees on these harsh sites generally ranged from 8 to 20 per ha (3-8/ac) (EOARC data file). Old growth stands in the ash-pumice zone of Mt. Mazama and Newberry Crater in central Oregon are more extensive (personal observation by authors). However, during the last 100 years, western juniper has increased in distribution and density throughout its range, expanding into open meadows, grasslands, sagebrush steppe communities, aspen groves (Eddleman 1987a, Miller and Rose 1995, Young and Evans 1981), and riparian communities (personal observation).

In central Oregon, in 1825, Peter Skene Ogden observed only occasional juniper trees (reported as cedars) growing on the hillsides while traveling through the Crooked River drainage (Rich et al. 1950). Today, these hillsides are covered by dense juniper woodlands. In a nearby area, J.W. Meldrum's 1870 survey notes describe a gently rolling landscape covered with an abundance of perennial bunchgrasses and a wide scattering of juniper trees (Caraher 1978). Today, juniper densities on this site vary between 125 and 250/ha (51 and 101/ac). Near Silver Lake, Oregon juniper density increased from about 17/ha (7/ac) in 1890 to over 400/ha (162/ac) by 1970 (Adams 1975). The majority of trees were established between 1902 and 1936. On another site in central Oregon, where these trees were absent prior to 1880, juniper increased to about 1018/ha (412/ac) by 1980 (Eddleman 1987a). In southeastern Oregon in 1901, Griffiths, a representative from the Department of Agriculture, was sent to tour and evaluate the condition of the western rangelands. He observed only scattered stands of juniper on Steens Mountain and across other parts of southeastern Oregon (Griffiths 1902).

Western juniper began increasing in both density and distribution in the late 1800s (Eddleman 1987a, Miller and Rose 1995, Young and Evans 1981). Current densities of trees less than 100 years old on the more productive low sagebrush and mountain big sagebrush communities on Steens Mountain average 338/ha (137/ac) (Miller and Rose 1995). In stands where juniper has invaded and completely replaced aspen trees on Steens Mountain, densities of old juniper trees ranged from 725 to over 2,000/ha (293 to 809/ac) (Miller and Rose 1995). The oldest juniper trees in these stands were less than 90 years old. Although western juniper is a long lived species, the oldest tree reported in eastern Oregon was aged at 886 years (Holmes et al. 1986), the majority of present day woodlands in eastern Oregon are less than 100 years old (USDI-BLM 1990).

Throughout eastern Oregon and northeastern California, western juniper expansion began in the 1880s. Well developed western juniper woodlands in central Oregon (EOARC data file, Eddleman 1984), and Juniper Hill in northeastern California (Young and Evans 1981) began establishment in the late 1800s, however, peak establishment occurred between 1890 and 1930. In southeastern Oregon, juniper expansion also began in the 1880s, however, establishment progressed slowly during the early 1900s, with the rate increasing later into the century as trees reached maximum potential reproductive maturity (Eddleman 1984, Miller and Rose 1995). Seed dissemination occurs primarily through movement by water across the land surface, particularly on frozen soils (Eddleman 1984), and through bird, coyote, and rabbit dispersal (Gabrielson and Jewett 1970). The Townsend solitare (*Myadestes townsendii*) (Lederer 1977, Poddar and Lederer 1982), the American robin (*Turdus migratorius*), Steller's jay (*Cyanocitta stelleri*), and scrub jay (*Aphelocoma coerulescens*) are primary avian vectors of juniper seed dispersal in the Great Basin (Gabrielson and Jewett 1970).

Factors most frequently implicated in the recent expansion of juniper species throughout the west are climate, fire, and grazing. The combined affect of climate and fire were likely the cause of juniper expansion and retraction during prehistoric times, but climate change and altered fire regimes may not be fully responsible for the expansion of western juniper woodlands during the last 100 years. Following the end of the Little Ice Age in the mid 1800s, winters became more mild and precipitation increased above the current long-term average between 1850 to 1916 in the northern Great Basin (Antevs 1938, Graumlich 1985, Holmes et al. 1986). Mild conditions and increased precipitation during the late 1800s and early 1900s, which promotes vigorous juniper growth (Earle and Fritts 1986, Fritts and Xiangdig 1986), increased the potential for juniper establishment. In central Oregon, juniper establishment primarily occurs during years of good tree-ring growth, with few trees establishing in years of marginal tree ring growth (Adams 1975). However, these conditions would also have increased the potential for fire due to the increased production of light fuels; grasses and forbs.

Reduced fire frequency has been one of the factors attributed to expansion of juniper throughout the west (Burkhardt and Tisdale 1976, Young and Evans 1981). Before settlement, fire frequencies in mountain big sagebrush (*Artemisia tridentata* spp. *vaseyana*) communities varied from 15 to 25 years (Burkhardt and Tisdale 1976, Martin and Johnson 1979, Houston 1973). Western junipers less than 40 to 50 years old are easily killed by fire (Burkhardt and Tisdale 1976). Fire probably maintained both shrubs and trees at low densities and often restricted trees to harsher sites, with little contiguous fuel.

Reduction of fire frequencies at the time of settlement was probably due to a decline in fires set by Native Americans and the reduction of fine fuels through livestock grazing. The effects of fire suppression during the late 1800s and early part of this century were minimal, not becoming a factor until after World War II. Native American-caused fires augmented lightning fires in the more mesic sagebrush communities (Agee 1993). Fire was used to improve forage for game, maintain or increase the yield of certain wild edible plants, and increase seed production. However, the influence of Native Americans declined as early as the late 1700s. By the close of the eighteenth century, native populations throughout the Intermountain Region were reduced 80 percent by European diseases such as smallpox, measles, venereal disease and possibly typhus (Thompson 1916, Cressman 1981). Despite their decline in population, Peter Skene Ogden noted abundant evidence of Native American set-fires in the Harney and Malheur Lakes region of southeastern Oregon during the middle 1820s.

Settlement of the region by European Americans in the late 1800s and early 1900s, led to a reduction of fine fuels due to grazing by high densities of domestic livestock (Griffiths 1902, Burkhardt and Tisdale 1976). Possibly the greatest influence livestock had on the expansion of juniper throughout the West was reduction of fine fuels resulting in a decrease in fire return intervals. In 1901, on his trip from Nevada to eastern Oregon, Griffiths (1902) stated; "No open-range lowland was seen on the whole trip which had much feed upon it excepting that consisting of the tough and persistent salt grass. On the whole trip of three days we found no good feed, except in very steep ravines." Removal of fine fuels was probably of particular importance during the wet and mild climatic conditions of the late 1800s and early 1900s, assisting the historic expansion of western juniper woodlands.

Competition appears not to be a factor inhibiting western juniper seedling establishment (Burkhardt and Tisdale 1976, Eddleman 1987, Miller and Rose 1995). Ecological condition of a plant community was not influential on seedling establishment. However, an increase in sagebrush would increase the number of safe sites for juniper seedling establishment since the majority of juniper seedlings are usually found beneath sagebrush canopies (Burkhardt and Tisdale 1976, Eddleman 1984, Miller and Rose 1995).

A more recent viewpoint attributes the expansion of pinyon-juniper woodlands in the southwest to increased atmospheric CO_2 concentrations (Johnson et al. 1990). Bazzaz et al. (1985) reported cool season C_3 plants respond more favorably to increased CO_2 levels than do warm season C_4 plants. In the southwest, increased atmospheric CO_2 may increase growth of cool season C_3 junipers at the expense of associated warm season C_4 grasses in the understory. In the northern portions of the juniper zone (i.e. western juniper) understory species are also cool season C_3 forbs and grasses. However, water use efficiency has been shown to be enhanced more in woody than herbaceous cool season plants (Polley et al. 1993).

Conclusions

Several factors appear to be different for juniper expansion in the prehistoric and historic record, including climate, fire frequency, plant community composition and structure, and atmospheric CO_2 levels. During prehistoric expansion, increased annual and growing season moisture coincided with downslope movement of juniper into drier shrub steppe communities (Wigand 1987). Pollen and charcoal records also suggest an increase in grasses in proportion to sagebrush and an increase in fire events in the region. In contrast, historic expansion of western juniper has occurred during a period of increasing aridity, decreasing fire return intervals, a decrease in the proportion of grasses to sagebrush, and introduction of new plants species. Historic expansion has occurred primarily within the upslope moist sagebrush steppe communities rather than downslope into the drier Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*) communities as it did in the prehistoric past. Western juniper also appears to have expanded slightly at higher elevations (e.g. above 2200 m on Steens Mountain) suggesting milder winter conditions than during prehistoric expansion. The increase in atmospheric CO_2 levels may have also contributed to recent juniper expansion in the West.

The development of these present-day woodlands under a different combination of environmental variables has led to woodland communities with a different plant composition and structure than those of the past. Current conditions have allowed present day juniper woodlands to become considerably more dense than in the recent past. In the 5,000 year pollen record at Diamond Pond, levels of western juniper pollen are greatest in the 20th century (Mehringer and Wigand 1990). Current climatic conditions are also less favorable for the development of a competitive herbaceous understory than in the past and may enhance the invasion of introduced weedy species. Greater tree densities under drier conditions obviously will have a very different impact on watershed properties, nutrient cycling, fauna, biodiversity and ecosystem processes than the scattered juniper communities of the past.

Biology of Western Juniper

Vasek (1966) characterized the western juniper tree as single stemmed, excurrent branched with a rounded to conical shape. Leaves are 3 mm long, scale-like, usually in 2s or 3s, rather blunt with ciliolate - denticulate margins. Leaves are dorsally glandular with a large drop of resin present which dries to white in the fall. Ovulate cones are bluish black, 7-8 mm long and 1-3 seeded. Bark is reddish to cinnamon brown and either shreddy or fissured (Hitchcock et al. 1969).

Vasek (1966) noted that western juniper has 2 to 4 cotyledons in the embryos and usually 2 in seedlings. Plants are monoecious or dioecious. He reported that for 631 specimens examined in the field 48% were monoecious, 41% were female, and 11% were male trees. Although Vasek found a sex expression change for *J. o.* ssp. *australis* and for Utah juniper he does not mention it for the northern race. Since he considers ssp. *J. o.* ssp. *occidentalis* a recent derivative of ssp. *australis* and that it likely hybridizes with Utah juniper, sex expression change is likely.

Sex expression may be partly controlled by the environment with maleness associated with xeric or moisture stress situations and femaleness associated with more moist situations as shown for Utah juniper (Freeman et al. 1981). This is also indicated by Miller and Rose (1995) who found male:female ratios of 1.7 to 1 in scattered stands and 3.8 to 1 in closed stands on Steens Mountain.

Eddleman (1987b) examined a young established woodland in central Oregon and reported that for 171 (tree density was 287/ha or 116/ac) reproducing trees examined over a three year period, 6% produced male cones only, 53% produced female cones only and 41% were monoecious. In a further examination of more open establishing woodlands in the same area, 97 reproducing trees (tree density of 98/ha or 40/ac) 10% were male, 40% were female and 50% were monoecious. In the established stand abundant berry production of 40 to 50 berries per m^2 of canopy surface occurred in 4% of the trees whereas in the establishing stand 42% produced abundant berries.

Male cones are initiated in the summer, mature and shed pollen the following spring. Female cones (berries) are first seen in mid winter, grow to full size the first year, reach maturity the second year, and fall off during the second autumn and winter period (Vasek 1966).

Significant seed production can be initiated between 50 and 70 years of age (Eddleman 1984, Miller and Rose 1995) and between 2 and 3 m (about 6 to 10 ft) in height (Eddleman 1987a). Berry production by individual western juniper trees in northeastern California were; 35% produced 0 berries, 24% produced 1-20 berries, 21% produced 20-100 berries and the remaining 20% produced up to 10,000 berries (Lederer 1977). Most of the berries were in the 2 to 4 m (6.5 to 13 ft) zone above the ground and on the outside of the canopy.

Dealy (1990) states that good seed production in western juniper occurs nearly every year. This may be true for the woodland regions as a whole but less so locally. Additionally, seed production has not been monitored over time, nor correlated to environmental factors.

Seeds are dispersed during early fall and winter of the second year. Seeds are dispersed horizontally by several vectors. Few of the dispersing agents have been researched, most information is anecdotal. Johnsen (1962) cites birds, rabbits and coyotes as mechanisms of juniper seed dispersal in the southwest. Eddleman (1984) observed western juniper seed dispersal by water flowing across frozen soil.

Lederer (1977), and Podder and Lederer (1982) show a strong dependency of Townsend's solitare on western juniper berries as a food source, and observed American robins, Steller's jays, and scrub jays eating western juniper berries and apparently competing with Townsend's solitaires. American robin and cedar waxwing were found to be major consumers of ashe juniper (*Juniperus ashes*) fruit on the Edwards Plateau, Texas (Chavez-Rimirez and Slack 1994). Eight other bird species were observed to feed on ashe juniper fruit including the mountain bluebird.

As with the Townsend's solitare, probably all consumers are after the food value of the pulpy seed covering, defecating the seeds throughout their home range. Some winter feeding bird species appear to have a rather high daily intake of juniper berries becoming important vectors for seed dispersal. An estimated 80 western juniper berries per day (850 cal of pulp per berry) are needed by captive solitares to meet their nutritional needs (Podder and Lederer 1982). However, uncaged birds in the woodlands would have nutritional needs of 2.0 to 2.5 times that of caged birds. Solomonson and Balda (1977) measured a daily intake of 204 one-seed juniper (*Juniperus monosperma*) berries (316 cal of pulp per berry) by caged solitares in an Arizona study.

Ashe juniper (*Juniperus ashei*) berry intake by American robin on the Edwards Plateau of Texas has been estimated at 555 berries per day (Chavez-Ramirez and Slack 1994). Although the large flocks of this bird species are frequently seen during the winter period in western juniper these researchers found average flock size in ashe juniper to be 10.4 birds. Flock consumption per day was placed at about 5,800 berries with mean post-foraging perch sites located 44 m from feedings trees. Woody vegetation was selected for post-foraging perch sites and few seeds were found away from woody vegetation.

Burkhardt and Tisdale (1976) measured a 1.29 m (4.2 ft) downslope movement of seed over a 6 month period during the winter period. Movement upslope, apparently due to animal disturbance, was found at other times of the year.

Germination in western juniper seed has been researched by Young et al. (1988) over a 10 year period. Seeds are highly dormant at maturation. In laboratory tests 14 weeks of cool (5°C) moist stratification produced maximal emergence of 10% to 37%

depending on the year the seed was produced. Field stratification at 1,690 m (5,540 ft) elevation yielded 45% to 93% emergence with 10 weeks of cumulative stratification over a four year period. Shorter and longer stratification periods yielded less emergence and total cumulative emergence was found to be year dependent. Most seeds remain dormant. The fruit coat, stony seed coat and embryo all may play a role in dormancy. These data indicate that germination and emergence likely takes place over a period of several years. The authors note that potential germination is high if all requirements are met which involves some form of prolonged cool-moist stratification. They also point out that stratification enhancement of germination is cumulative from year to year.

The preponderance of seedling establishment by western juniper takes place beneath sagebrush plants (Burkhardt and Tisdale 1976, Eddleman 1987, Miller and Rose 1993); however, establishment conditions appear favorable as well beneath other shrubs and trees. In closed juniper stands, establishment may be mostly beneath older trees (Miller and Rose 1995). Open areas between established plants are usually not sites of establishment. High sagebrush densities create a situation of high density of safe sites. Sagebrush plants might provide protection from environmental stress since juvenile foliage has relatively poor stomatal control and is less water use efficient than adult foliage (Miller 1990). Young junipers, 2 to 20 years old, have been found to grow faster under sagebrush plants, 3.4 cm (1.3 in)/yr as compared to intercanopy areas of 2.4 cm (1 in)/yr (Miller and Rose 1995), indicating that reduced environmental stress and nutrient availability may be important. Burkhardt and Tisdale (1976) gave average growth rates of western juniper seedlings as 1.4 to 3.4 cm (0.6-1.3 in)/yr with factors such as soil moisture, radiation, soil texture (fines), bulk density, and total shrub density as important variables for growth.

Growth rates may be very slow during the first few years of a western juniper's life beneath sagebrush plants. Kramer (1990) reported a mean height of 5.3 cm (2 in) for a mean age of 3.1 years. This growth rate (1.7 cm/yr) was not greatly different for plants with a mean height of 62.3 cm (24.5 in) and a mean age of 33 years (1.8 cm/yr). Plants studied were in an open mixed age class juniper woodland with numerous mature trees present. Roots of adult trees were mixed with seedling and juvenile roots to the extent that competition could have affected growth in the younger plants.

Eddleman (1987) reported height growth to range from 9.0 to 16.7 cm (3.5-6.6 in)/yr for the oldest dominant trees in a young woodland located on moderately deep soil with a northerly aspect. These trees were over 90 years old and represented only 4% of the population (average of 40 of 1,018 trees/ha — 16 of 412/ac). Trees recruited at a time when the dominant trees were 60 or more years old had growth rates ranging from 2.3 to 3.2 cm (0.9-1.3 in)/yr which is similar to growth rates cited above.

Root growth data is limited to studies by Kramer (1990) from central Oregon and Young and Evans (1984) from northeastern California. Kramer excavated trees (n=41) ranging in age from 2 to 34 years in pumice derived soil which was about 70 cm (28 in) deep over fractured rock. Rooting depth was achieved early on by a slowly developing taproot with very little lateral root growth up to 10 years of age. The taproot was about 20 cm (8 in) deep at 3 years of age while trees 23 years old had penetrated the fractured rock. The taproot was retained in all individuals, for those of the 31 to 34 year age class it still contributed 34% of the root biomass. Young and coworkers (1984) however did not find taproots on older trees. The taproot may degenerate with age or development may be facultative. Lateral root spread (diameter) was very slow up through 6 to 10 years, about 1.5 cm/yr (0.6 in), however the 11 to 15 year age class had increased lateral growth to over 6 cm/yr (2.4 in) which was roughly sustained through the 31 to 34 year age class.

Using north to south trenches Young and Evans (1984) examined the roots of young but old western juniper trees (n=10). Soils were about 100 cm (39 in) deep and canopy cover approximately 40%. Root mass was highest near the bole and consisted of large concentrations of fine roots. At 6 m (19.7 ft) from the bole roots of adjoining trees were thoroughly mixed. In the area 1 m (39 in) or more away from the bole, root distribution showed no decline in root mass with increasing distance from the bole and no decline with soil depth except for depths over 75 cm (29 in) where few roots were found. Within this outer zone, root mass ranged from 27 to 74 g/dm^3 while at the bole, root mass ranged from 85 from 184 g/dm^3.

Both studies show that a fine root (< 1 mm diam.) mass develops strongly around the tree bole and at the ends of laterals.

Stand structure in western juniper woodlands takes on different forms with even-age stands occupying twice the area of uneven-aged stands, 586,200 ha vs. 293,000 ha (1,448,500 ac vs. 724,000 ac) (Oswald 1990). However, uneven-aged stands over 100 years old occupy almost four times as much area as even-aged stands, 65,100 ha vs. 16,300 ha (160,862 ac vs. 40,277 ac). Some other age classes show marked differences in stand structure relative to establishment years. Young woodlands tend to be much more even-aged than old woodlands (Burkhardt and Tisdale 1969, Young and Evans 1981, Adams 1975).

Young and Evans (1981) measured 150 trees/ha (61/ac) on big sagebrush sites, 28/ha (11/ac) on low sagebrush (*Artemisia arbuscula*) sites and 25/ha (10/ac) on bitterbrush (*Purshia tridentata*) sites. Stands on the big sagebrush site tended to be more even-aged than those on low sagebrush sites although considerable variation in height and canopy diameter occurred on the big sagebrush sites. They concluded that population growth during the establishment phase in the big sagebrush sites was one of doubling every three years. For low sagebrush sites and for big sagebrush sites after 1910, populations were doubling about every 48 years.

Closed stands of western juniper on Steens Mountain (Miller and Rose 1995) were reported to have densities of 876/ha (354/ac) in mountain big sagebrush sites and 257/ha (104/ac) on low sagebrush sites. The big sagebrush site had 580 juveniles/ha (235/ac) (<.05 m (1.6 ft) tall) while the low sagebrush site had 99 juveniles/ha (40/ac).

Tree densities ranged from 138 to 425/ha (56 to 172/ac) for old woodlands and from 99 to 504/ha (40 to 204/ac) for young woodlands on the Owyhee Plateau (Burkhardt and Tisdale 1969), although densities of 2,076 adult trees/ha (840/ac) were found. Miller and Rose (1995) reported tree densities of over 18,000/ha (7,284/ac) on aspen sites on Steens Mountain with mean densities of 10,854/ha and 3,906/ha (4,392/ac and 1,581/ac) for late and intermediate stages of succession respectively. High densities of adult trees are not uncommon. In central Oregon mean densities of juniper trees in young woodlands were 100 adult/ha (40/ac) and 918 juveniles/ha (372/ac) (Eddleman 1987). In the Silver Lake area Adams (1975) found a mean density of 410 trees/ha (166/ac).

High canopy cover values are as common in the literature as low cover values. In general, juniper canopy cover is highest on moist sites and least on xeric sites. Juniper canopy cover up to nearly 100% in aspen stands has been reported by Miller and Rose (1995) although closed juniper stands in low sagebrush sites had a mean cover of 15% and those on mountain big sagebrush sites had a mean cover of 22%. Oswald (1990) reported over 114,000 ha (281,700 ac) of western juniper woodland in Oregon with an average canopy cover of 45%.

Mortality factors appear to be nearly absent from western juniper woodlands. The general consensus is that insects and disease, though common, cause little mortality. Authors comment on the low frequency of dead and dying trees on their study sites.

The primary mortality factor operating in western juniper stands is fire. Martin (1978) states that trees under 2 m (79 in) tall are easily killed by fire but as trees become larger greater intensities are required. Closed stands burn poorly due to lack of fuel both between and beneath canopies.

Insects and diseases of western juniper have been little studied, although the recent rise in its commercial value will likely increase the studies on factors that decrease wood value and increase mortality. The following information on insects and diseases are taken from: Dealy 1990, Hepting 1971, Jaramillo 1980, Keen 1952, Pertini and Carroll 1981, Sowder and Mowat 1958, Vasek 1966, and Varughese and Calvin 1984.

Insects and Diseases

Insects which predate western juniper include:

Mehia juniperi and *Styloxus bicolor* – Long-horned beetles, girdle limbs and twigs

Phloeosinus serratus Juniper bark beetle

Callidium californicum and *C. juniperi* – Round head borers of twigs and limbs

Ithome sp. (caterpillar) and *Melanoplus sp.* (grasshoppers) – feed on berries and leaves.

Disease and parasitic agents which infect western juniper include:

Pyrofomes demidoffii - White trunk rot

Fomes juniperinus ≠ F. texanus – wood rots

Unidentified brown cubical rot found in the base

Phomopsis sp. – juniper blight

Retinocyclus abietis, Kabatina Juniperi, and Hormoneme sp. Endophytic fungi on foliage

Phoradendron juniperinum and P. bolleanum Mistletoes, twig parasites

Arceuthobium campylopdum - dwarf mistletoe, twig parasites

Gymnosporangium kernianum, G. betheli, and other species of this genus - Witches' brooms, a rust, girdles and kills branches.

Physiological Ecology of Western Juniper and Associated Species

Introduction

The focus in this section is on the physiological ecology of western juniper and other species, commonly associated with it in western juniper woodlands, for which data are located in the literature search. Other species included are: gray rabbitbrush *(Chrysothamnus nauseosus)* green rabbitbrush *(C. viscidiflorus),* Sandberg wheatgrass *(Poa sandbergii),* and Idaho fescue *(Festuca idahoensis).* The data on gray rabbitbrush are from a Utah juniper area in Utah, and data on bluebunch wheatgrass are from a grassland in western Washington. These data sets are included because data on these species are very limited.

Mountain big sagebrush and bluebunch wheatgrass (*Agropyron spicatum*) are also commonly associated with western juniper. The literature search did not encounter research articles on the physiological ecology of these species in western juniper woodlands. However, literature is readily available on the physiological ecology of mountain big sagebrush and bluebunch wheatgrass in other ecosystems and will not be included here. Much of the research on the physiological ecology of these two species has been conducted by the research group at Utah State University. Papers co-authored by Dr. M. M. Caldwell are appropriate.

The literature search did not encounter data on the physiological ecology of bitterbrush (*Purshia tridentata)*, gray horsebrush (*Tetradymia canescens*), or squirreltail (*Sitanion hystrix*).

Western Juniper — Patterns in Biomass Allocation

Above- and belowground biomass allocation of western juniper were measured at a site 12.8 km (8 mi.) west of Redmond, OR (44°16'48"N, 121°20'30"W) on a west facing slope at 1,050 m (3,445 ft) elevation (Kramer 1990). Soils averaged 70 cm in depth and were developed from volcanic ash. Vegetation at the site was similar to the *Juniperus/Artemisia/Agropyron-Chaenactis* community described by Driscoll (1964b).

Forty-one individuals, including root systems, were collected as a stratified random sample from seven tree height classes, 0-5, 10-20, 20-30, 30-40, 40-50, and 50-75 cm (Kramer 1990). Trees were divided into shoot and root system. Aboveground components of each tree were divided into juvenile foliage, adult foliage, branches, trunk, and dead tissue. Belowground structures were divided into taproots and lateral roots and into 3 size classes, fine roots (<1 mm diameter), medium roots (1-5 mm), and coarse roots (>5 mm). Maximum rooting depth and horizontal root extension were measured during excavation. Root system length was calculated from length/weight ratios and from direct measurements. Summary statistics were calculated and least squares regression techniques were used.

Trees ranged in height from 3.9 to 75 cm (1.5 to 29.5 in) and were 2 to 34 years old (Kramer 1990). Root system development progressed through three phases. During the first phase (tree age ≤ 10 years), the root system is dominated by a long slender taproot with few laterals. Mean root depth for trees less than 6 years was 20 cm (7.9 in) with mean lateral root extension of 3 cm (1.2 in). For trees 6-10 years, mean root depth was 34 cm (13.4 in) with a lateral root extension of 13 cm (5.1 in).

From age 11-25 years, the general character of the root system changed (Kramer 1989). The taproot became less dominant and lateral root expansion increased. Sixty-four to 70% of the lateral roots emerged between 5 and 20 cm (2 and 7.9 in) depth. Large lateral roots developed secondary and tertiary laterals. Very few woody laterals grew vertically and formed sinker roots.

During the third phase (age >25 years), the form of the root systems was similar to that during phase two, but root system dimensions increased as a result of both lateral and taproot growth (Kramer 1990). Lateral root expansion was more pronounced with fine lateral roots forming a dense mat of roots close to the tree crown in a volume of soil approximately one-third of the diameter of the root system and about 20 cm deep. Fifty percent of the lateral roots originated between 5 and 20 cm depth. With progressing age, root systems were composed mainly of lateral roots. Almost 70% of the biomass and 90% of the root length was in lateral roots in the oldest trees excavated. The largest tree had 132 grams of roots with a total length of 292 m (958 ft).

Root dry mass as a percentage of the total tree biomass was highest in young trees and gradually decreased to less than 40% in the oldest individuals (Kramer 1990). A series of regressions for the relationship between tree components and tree age were developed (Table 1). Tree age was a good predictor of total belowground biomass ($r^2 = 0.90$), total root system length ($r^2 = 0.88$), and total aboveground biomass ($r^2 = 0.89$).

<u>Western Juniper — Allocation Patterns of Carbon and Minerals</u>

Seven trees with 100% juvenile foliage and seven with both juvenile and adult foliage (Kramer 1990) were excavated to determine the allocation patterns of carbon and minerals in juvenile and small-adult western juniper (Miller et al. 1990). Roots were divided into three diameter size classes: <1 mm, 1-5 mm, and >5 mm. The aboveground portion of each tree was divided into juvenile foliage, adult foliage, and non-green branch/trunk. Because of the awl-like and scale-like morphology of juvenile and adult western juniper foliage, no attempt was made to separate leaves from green stems.

Kjeldahl nitrogen and macro- and micronutrient elements were measured (n=7) for each tissue type. Construction cost (CC) of each tissue type was calculated using the equation:

Table 1. Relationships between tree components (y) and tree age (x).

Tree component y	N	Intercept a	Slope b	r^2	E, e	C.F.
Tap root depth (cm)	41	2.19	0.87	0.84	1.33	0.04
Lateral spread (cm)	41	-1.33	1.93	0.88	1.96	0.23
Taproot biomass (g)	40	-6.79	2.68	0.92	2.14	0.29
Lateral root biomass (g)	40	-7.70	3.14	0.88	2.99	0.60
Fine root biomass (g)	40	-5.85	2.30	0.87	2.25	0.33
Coarse root biomass (g), $x \geq 7$	27	-10.47	4.12	0.71	3.11	0.64
Total belowground biomass	40	-6.49	2.91	0.90	2.50	0.42
Taproot length (cm)	40	1.14	1.55	0.87	1.77	0.16
Lateral root length (cm)	40	-0.56	2.82	0.89	2.50	0.42
Fine root length (cm)	40	0.88	2.30	0.87	2.25	0.33
Coarse root length (cm), $x \geq 7$	27	-4.91	3.87	0.70	3.02	0.61
Total root system length (cm)	40	0.73	2.44	0.88	2.28	0.34
Juvenile foliage biomass (g)	41	-6.77	2.70	0.85	2.91	0.57
Adult foliage biomass (g), $x \geq 17$	18	-77.39	3.98	0.46	0.87	
Total foliage biomass (g)	41	-7.31	3.08	0.86	3.13	0.65
Structural biomass (g)	41	-8.53	3.41	0.91	2.77	0.52
Dead biomass (g)	41	-7.67	2.49	0.84	2.76	0.52
Total aboveground biomass (g)	41	-6.62	3.08	0.89	2.75	0.51
Total plant biomass (g)	40	-5.81	2.97	0.89	2.60	0.46
Height (cm)	41	-0.50	0.99	0.88	1.40	0.06

The regression model used was $\ln y = a + b \ln x$ for all variables except adult foliage biomass, which was analyzed with $y = a + bx$. Regression constants (a, b) and coefficients of determination (r^2) are given as computed; estimates of relative errors (E for logarithmic regressions, e for linear regression) are listed in arithmetic units. Correction factors (C.F.) are given for each logarithmic regression (from Kramer 1990).

$$CC = \{(0.06968 * dH_c - 0.065)(1-A) + \frac{kN}{14.0067} * \frac{180.15}{24}\} * \frac{1}{E_g}$$

Where dH_c is the heat of combustion, A is the ash content, kN the total Kjeldahl nitrogen of the tissue, and E_g the growth efficiency (Williams et al. 1987). A value of 0.87 was used as an estimate of growth efficiency (Penning de Vries et al. 1974). Uncorrected values for heat of combustion were used to calculate tissue construction cost.

Of the tissue analyzed, adult foliage had the highest heat of combustion, 20.9kJ/g; significantly higher than juvenile foliage on the same individual or juvenile foliage on juvenile trees (Miller et al. 1990). Aboveground and belowground tissue contained 17-23% ash with no difference in juvenile and small adult tissue. Adult foliage had the highest construction costs 1.33 ± 0.9 g glucose/g dry mass, significantly higher than the cost of producing juvenile foliage on small adults (1.26 ± 0.1 g glucose/g dry mass) or on juveniles (1.21 ± 0.12 g glucose/g dry mass) ($P < 0.025$). Sixty-two to 65% of the total plant construction was in aboveground tissue for both juvenile and small-adult western juniper.

Adult foliage had significantly higher nitrogen concentrations, 1.23% ± 0.04, than did juvenile foliage on small adults or on juveniles, 1.10% ± 0.05 and 1.14% ± 0.07, respectively (Miller et al. 1990). Concentrations of macronutrient elements relative to biomass indicated that nitrogen, potassium, calcium, and magnesium were concentrated in metabolically active leaf tissue. Aboveground biomass contained 72-75% of the total plant nitrogen.

Juveniles allocated significantly less dry mass to aboveground biomass than did small adults, 57 vs. 60% (Miller et al. 1990). Juveniles allocated a higher percentage of dry mass to roots <1 mm diameter than did small adults; over half of the total belowground dry mass of both plant types was in the 1-5 mm diameter root class. Ratios of roots <1 mm diameter to green foliage were significantly higher for juveniles, 0.29-0.47, than for small adults 0.17-0.28.

Western Juniper — Biomass and Leaf Area Estimators

Western juniper trees used to develop regressions for estimating component biomass, volume, surface area, and biomass increment were located along an northeast-facing slope at the summit of Horse Ridge in central Oregon at an elevation of 1,356 m (4,449 ft) (Gholz 1980). Soils were extremely stony and about 65 cm deep, derived from aerially deposited pumice above closely packed, fractured basalt bedrock. Vegetation at the site was classified as juniper/sagebrush community type.

All live trees in seven 20-m-radius circular plots randomly located within a 1 ha area were nondestructively measured (n'). Ten western juniper, randomly selected from three size classes (0-75, 76-150, >151 cm (0-29.5, 30-59, ≥ 59.5 in) in basal circumference) were destructively analyzed (n). Stems and branches were subsampled, dried, and weighed. Surface areas of subsamples were estimated and net aboveground primary production was estimated as the average annual biomass increment over the last five years (Gholz 1980). Regressions were developed using basal circumference as the independent variable.

The study area had 246 ± 20/ha (99.5 ± 8/ac) live western juniper (Gholz 1980). Dimensions of live western juniper, regression equations for estimating component biomass, and average dimensions of western juniper estimated by double sampling are given in Tables 2, 3, and 4. Wood specific gravity averaged 0.50 g cm^{-3} (SD 0.05, n = 20) with a range of 0.437 - 0.678 g cm^{-3}. Specific leaf area of the trees sampled was 44.0 cm^2 g^{-1} (SD 2.0, n = 27). Net production estimates for stem, branch, and foliar biomass increments were 195, 2, and 900 kg ha^{-1} y^{-1} (174, 1.8, and 804 lbs/ac), respectively. The total net production estimate was 1,097 kg ha^{-1} y^{-1} (980 lbs/ac) (Gholz 1980), which ranks his western juniper community among the least productive of mature evergreen tree communities in the world (Art and Marks 1971).

A second study examined the relationship between sapwood area and basal circumference of western juniper in southeastern Oregon (Miller et al. 1987) where 13 western juniper ranging in circumference from 9 to 263 cm (3.5 to 103.5 in) were destructively harvested to develop a nondestructive technique for estimating leaf area and leaf biomass. Trees were harvested at the Northern Great Basin Experimental range located on the northern fringe of the Great Basin in southeastern Oregon at 1,350 m (4,429 ft) elevation.

Thirteen trees were cut off at the soil litter surface (Miller, et al. 1987b). The thirteenth tree was selected to represent the largest trees within the stand. Sapwood was measured at the base and midsection of the main trunk. All foliage was removed, dried for 72 hours at 60°C, and weighed. Foliage subsamples were taken for area measurements on a LiCor leaf area meter.

The following year six additional trees, ranging in basal circumference from 11 to 47 cm (4.3 to 18.5 in), were harvested and similar measurement made. The two populations had identical ratios; therefore, data for the two populations was pooled. Basal circumference, basal sapwood area, and midsection sapwood area were used as independent variable in regression analysis.

Leaf area and leaf weight were strongly correlated ($r^2 = 0.978$) as were all other variables tested (Table 5). However, caution should be used when extrapolating equations to trees larger than the largest trees used in this research, diameter = 82.8 cm (32.5 in), height = 9.8 m (32 ft). The regression model developed by Gholz (1980), by subsampling 10 trees, fits the data for this study for trees <30 cm (12 in) in circumference, but consistently underestimated leaf biomass for trees 30 to 137 cm (12 to 54 in) in circumference by 24 to 47% (Miller et al. 1987b).

Table 2. Dimensions of live junipers on Horse Ridge: n' = measured and n = the 10 destructively analyzed.

Dimension	$\bar{X}$ ± SE	Range	Coefficient of variation
Basal circumference (n')	120.07 ± 7.8 cm	10.5 - 317.0 cm	0.61
Basal circumference (n)	104.10 ± 25.0 cm	14.5 - 273.0 cm	0.76
Crown volume (n)	92.21 ± 44.05 m^3	0.64 - 303.46 m^3	1.36
Height (n)	4.45 ± 0.74 m	1.00 - 8.50 m	0.52
Sapwood basal area (n)	345.56 ± 103.61 cm^2	12.34 - 1098.06 cm^2	0.95

(from Gholz 1980)

Table 3. Regression equations for estimating component biomass, volume, surface area, and biomass treatment for western juniper with basal circumference (cm) as the independent variable. The first 12 follow the form $\ln(Y) = A + B*\ln(X)$ with variances ($S^2_{y,x}$) in logarithmic units. The last four are linear, untransformed equations with variances in arithmetic units.

Dependent Variable	**A**	**B**	**$S^2_{y,x}$**	**r^2**
Stem wood biomass (kg)	-8.5947	2.6389	0.029	0.995
Stem wood volume (cm^3)	-0.8568	2.6006	0.048	0.990
Stem bark biomass (kg)	-10.251	2.6333	0.152	0.974
Stem bark volume (cm^3)	-2.5414	2.6006	0.106	0.981
Whole stem biomass (kg)	-8.3939	2.6344	0.029	0.995
Whole stem volume (cm^3)	-0.6719	2.5977	0.135	0.965
Sapwood volume (cm^3)	0.7232	2.1313	0.135	0.965
Live branch biomass (kg)	-7.3115	2.3337	0.068	0.985
Dead branch biomass (kg)	-11.8460	2.8323	0.664	0.908
Leaf surface area (m^2)	-2.5917	1.5383	0.019	0.990
Leaf biomass (kg)	-4.2430	1.5606	0.024	0.988
Height (m)	-1.8676	0.7329	0.031	0.934
Leaf surface area (m^2) = 0.559 • (sapwood breast height, cm^2)			944.5	0.960
Leaf biomass (kg) = 0.140 • (sapwood breast height, cm^2)			56.6	0.966
5-year stem biomass increment (wood + bark, kg) = -0.383 + 0.0362 • (basal circumference)			0.930	0.910
5-year live branch biomass increment (wood + bark) = -0.344 + 0.0165 • (basal circumference)			0.356	0.840

(from Gholz 1980)

Table 4. Average dimensions of western juniper estimated by double sampling.

Dependent Variable	**Units per plant ($\overline{Y}_I$)**	**90% Confidence Interval ($\overline{Y}_I$)**	**Units per ha ($\overline{Y}_{tot}$)**	**90% Confidence Interval ($\overline{Y}_{tot}$)**
Stem wood biomass	30.5 kg	20.3 - 45.8 kg	7,505.7 kg	4,703.9 - 11,976.5 kg
Stem wood volume	59,700 cm^3	39,600 - 90,000 cm^3	14.7 m^3	9.2 - 23.5 m^3
Stem bark biomass	6.0 kg	3.9 - 9.4 kg	1,485.1 kg	897.1 - 2,458.6 kg
Whole stem biomass	36.5 kg	24.5 - 54.5 kg	8,989.7 kg	5,661.0 - 14,275.6 kg
Whole stem volume	70,812 cm^3	47,300 - 106,100 cm^3	17.4 m^3	10.9 - 27.8 m^3
Sapwood volume	35,600 cm^3	24,500 - 33,100 cm^3	8.8 m^3	5.6 - 13.7 m^3
Live branch biomass	28.0 kg	19.2 - 40.9 kg	6,894.9 kg	4,431.0 - 10,728.7 kg
Dead branch biomass	3.9 kg	2.1 - 7.2 kg	961.8 kg	500.4 - 1,848.6 kg
Leaf surface area	82.5 m^2	64.8 - 105.1 m^2	2.0 ha	1.5 - 2.8 ha
Leaf biomass	17.5 kg	13.7 - 22.5 kg	4,315.0 kg	3,072.9 - 6,059.4 kg
Total biomass	85.9 kg	59.5 - 125.1 kg	21,161.4 kg	13,665.3 - 32,912.3 kg

(from Gholz 1980)

Table 5. Regression equations, standard error of estimate (Sy,x) and correlation coefficients for estimating leaf biomass and leaf area.

n	Independent variable (X)	Dependent variable (Y)	Regression equation	Sy,x	Correlation coefficient
19	Leaf wt (g)	Leaf area (cm^2)	$Y = -40.566 + 65.238X$	107.010	0.978
19	Sapwood area (cm^2)	Leaf biomass (kg)	$Y = 1.237 + 0.024(X) + 0.00005(X^2)$	2.735	0.987
19	Sapwood area (cm^2)	Leaf area (m^2)	$Y = 8.145 + 0.155(X) + 0.00035(X^2)$	17.822	0.987
19	Basal circ. (cm)	Leaf biomass (kg)	$Y = -5.381 + 0.352(X)$	3.570	0.976
19	Basal circ. (cm)	Leaf area (m^2)	$Y = -35.036 + 2.296(X)$	23.294	0.976
13[1]	Sapwood area (cm^2)	Leaf biomass (kg)	$Y - 0.473 + 0.040 (X)$	0.445	0.938
13	Sapwood area (cm^2)	Leaf area (m^2)	$Y = 0.220 + 0.504(X) - 0.0024(X^2)$	3.250	0.906
13	Basal circ. (cm)	Leaf biomass (kg)	$Y = -1.046 + 0.143(x)$	0.391	0.953
13	Basal circ. (cm)	Leaf area (m^2)	$Y = -4.007 + 0.767(X)$	3.763	0.862

[1] Regression equations with n = 13 were developed for trees with basal circumferences less than 50 cm.

(from Miller et al. 1987)

Western Juniper — Leaf Morphology of Adult Foliage

Leaf samples for a study on the leaf morphology of adult western juniper foliage were collected at the Northern Great Basin Experimental Range, in southeastern Oregon.

Leaf samples were collected from branchlets on the north and south sides of trees (Miller and Shultz 1987). Entire branchlets and individual leaves were prepared for scanning electron microscopy.

Mature leaves of western juniper are reduced to small scales, which range from 0.9 mm to 1.2 mm in length, and have an average leaf area of 1.78 mm^2 (Miller and Shultz 1987). The leaves are triangular with minutely serrate margins. Leaf margins are slightly recurved creating a slight "cupping". Leaf epidermis is heavily cuticularized.

Stomates occur on both adaxial and abaxial surfaces. Adaxial surfaces are not exposed to sunlight or air movement and abaxial surfaces are only partially exposed. Stomata numbers, densities, and frequencies are 36-40, 21-22 per mm^2, 12.3%, respectively, on adaxial surfaces and 8-10, 4.7-5.7, and 3.0% per mm^2 on abaxial surfaces. Pore areas at apparent maximal stomatal opening are 1% of the total area on the adaxial surface and 0.25% on the abaxial surface. Leaf position did not affect stomatal size or density. Leaves sampled from the north an south sides of the tree had similar numbers and densities of stomates (Miller and Shultz 1987).

The absence of stomates on exposed leaf surfaces, thick cuticles, and reduced stomata density are mechanisms that reduce water loss through transpiration under high evaporative conditions. These adaptations allow western juniper to grow in the semiarid conditions of the Great Basin (Miller and Shultz 1987).

Western Juniper — Seasonal Ring Growth

Seasonal ring growth of western juniper was measured in the Leslie Gulch area of southeastern Oregon (Peter 1977). Trees were sampled near Dago Gulch in Malheur County, Oregon, at an elevational range of 1,170 m (3,839 ft) to 1,219 m (4,000 ft). The soil on the area was shallow, soft, porous, volcanic tuff. The area was extremely rocky; roots were confined to the top 30 cm (12 in) of substrate.

Increment cores were taken at weekly intervals from June 14 through August 21, 1975. All cores were taken from the same side of the tree at breast height. Data were analyzed using regression analysis and Student's t-tests.

Dry-site or ridge top trees had a slower growth rate and completed tree ring growth by August 6 (Peter 1977). Although dry site trees may have started growing earlier in the spring than trees on the moister site, moist site trees, or stream-side trees, grew more and were not fully lignified by August 26.

Tree rings indicated that western juniper grew appreciably in August when temperatures were favorable and soil water was available. False rings were produced in August and occurred more frequently in the moister-site trees than in the drier-site trees. False rings in drier-site trees were sharply delineated and difficult to separate from true rings (Peter 1977).

Western Juniper — Physiological Ecology

Research on the physiological ecology of western juniper was conducted at two locations in central Oregon, 12.8 km west of Redmond (44°15'N, 121°22'30'W) and south of Prineville (44°15'N, 120°45'W) (Miller et al. 1991a, 1991b, 1992, 1993, in press). The Redmond site, 1,050 m (3,445 ft) elevation, was a western juniper/ mountain big sagebrush community. The soils were from Mazama volcanic ash over tuff, with a uniform silt loam texture down to a hardpan at about 70 cm (27.5 in). Annual precipitation at Redmond averages 217 mm (8.5 in), 89% of which occurs from October to June (NOAA 1982).

The Prineville site, an abandoned agricultural field dominated by gray rabbitbrush and cheatgrass (*Bromus tectorum*) with western juniper scattered throughout, was last cultivated about 1975. Elevation was 1,270 m (4,167 ft). The soil was derived from basalt with a uniform sand loam texture down to a layer of fractured basalt at 50 cm (19.7 in). Annual precipitation at Prineville (elevation 868 m) averages 254 mm (12 in), 89% of which occurs between October and June (NOAA 1982).

Carbon dioxide assimilation and relative humidity were measured while leaf conductance, transpiration, and intercellular CO_2 concentrations were calculated. Photon flux density, leaf and air temperatures, and xylem pressure potentials were measured. Data were reduced using a BASIC program based on equations from Wexler (1976, 1977), Nobel (1983), Campbell (1986), and Ball (1987). Daily totals of CO_2 assimilation, transpiration, and photon flux density were calculated by integration under measured diurnal curves.

Western juniper has needle-like juvenile leaves which give way to scale-like adult leaves as the plant matures (De Laubenfels 1953). Physiological measurements were made on juvenile trees with needle-like foliage that averaged 35 cm (13.8 in) in height, on small adults that averaged 1 m (3.3 ft) in height with predominately adult scale-like foliage, and on large adult trees with an estimated average height of 4.5 m (14.8 ft).

A series of physiological measurements were made from July 1987 through October 1988 with 4 to 7 replicates. Tissue analysis for total Kjeldahl nitrogen and concentrations of macro- and micronutrient elements was conducted.

The highest rates of CO_2 assimilation for juvenile and small adult western juniper were measured in July, 22.0 ± 1.4 and 14.5 ± 1.4 nmol g^{-1} s^{-1}, respectively. The highest rates for large adult trees, 11.4 ± 1.2 nmol g^{-1} s^{-1}, were measured in April. Juvenile and small adults also took up the most CO_2 on a daily basis during July, 587 and 410 μmol g^{-1}

day^{-1}, respectively. Large adults total daily assimilation was highest during August, 324 μmol g^{-1} day^{-1} (Miller et al. 1991a, Miller et al. 1992).
The highest conductance was measured early in the summer, but the highest transpiration occurred during July when vapor pressure deficits were high. Leaf conductance flux density was highest for juveniles in June, 909 μmol g^{-1} s^{-1}, for small adults in April, 616 μmol g^{-1} s^{-1}, and for large adults in June, 346 μmol g^{-1} s^{-1}. The largest daily total transpiration was measured during July and was 299, 173, and 166 μmol g^{-1} day^{-1} for juveniles, small adults, and large adults, respectively.

Daily transpirational loss of water appeared to be controlled more by environmental conditions of soil moisture availability and vapor pressure deficit than by the physiological mechanism of stomatal opening and closing. Diurnal curves of conductance on days when soil moisture and vapor pressure deficits were high and on days when both were relatively low indicated a similar degree of stomatal opening in juvenile and in large adult western juniper (Miller et al. 1993).

The calculated daily total CO_2 assimilated and daily total water transpired for an average sized large-adult western juniper 4.5 m (14.8 ft) tall with a basal circumference of 66 ± 4 cm (26 ± 1.6 in) ranged from a high of 260 g of CO_2 assimilated with a water loss of 54 l in August to a low of 4 g of assimilation in November and 2 l of water lost in January (Table 6) (Miller et al. 1992).

When ranked over the 15 month measurement period, daily total water use efficiency (daily total CO_2 assimilation per daily total transpiration) of juvenile, small- adult, and large-adult western juniper was not significantly different and ranged between 1 and 2.5 (μmol $H_2O)^{-1}$ g^{-1} d^{-1}.

Juvenile western juniper had more negative xylem pressure potentials than did small adults or large adults when soil gravimetric water content was below 7%, during October and November, 1987, and July, August, September, and October, 1988. The most negative predawn xylem pressure potentials ranged from -3.8 MPa for juveniles to -3.1 for large adults; the most negative midday potentials ranged from -5 MPA for juveniles to -4.2 MPa for large adults. Small adult potentials were intermediary between those of juveniles and large adults.

Foliar nitrogen concentrations were highest during July for juveniles and small adults, 1.36 and 1.32% respectively, and highest in large adults in October and February, 1.25%. (Miller et al. 1991a, 1992). Potential photosynthetic nitrogen-use efficiencies [the maximum CO_2 assimilation rate measured each month (μmol g^{-1}) per nitrogen concentration in foliage used for the assimilation measurements (mol g^{-1}), PPNUE] (Field and Mooney 1986) was higher for juveniles than for both small adults and large adults when PPNUE was compared over the 15 month measurement period (Miller et al. 1992).

Concentrations of macro- and micronutrient elements in juvenile, small adult, and large adult foliage did not vary in any constant pattern. The range of concentrations of macronutrients through the year was: phosphorus 0.14 - 0.29%, potassium 0.3 - 0.98%, calcium 0.95 - 1.68%, magnesium 0.15 - 0.23%. The range of micronutrients was: zinc 8 - 17 ppm, copper 0.32 - 1.6 ppm, iron 203 - 1007 ppm, manganese 16 -

Table 6. Daily total CO_2 assimilated in grams per tree and daily water transpired in liters per tree, during a full sun day, for the average sized large-adult western juniper, 4.5 m tall with a basal circumference of 66 ± 4 cm.

Year	Month	Assimilation (g)	Transpiration (1)
1987	July	246	54
1987	August	260	54
1987	October	114	n.d.
1987	November	4	6
1988	January	9	2
1988	April	200	34
1988	May	160	37
1988	June	160	43
1988	July	146	31
1988	August	225	40
1988	September	85	27
1988	October	54	19

(from Miller et al. 1992)

43 ppm, boron 11 - 22 ppm, sodium 81 - 431 ppm, aluminum 202 - 1348 ppm, and silica 1405 - 3967 ppm (Miller et al. 1992).

Specific leaf weight of juvenile, small-adult, and large-adult western juniper foliage ranged from 106 to 256 g m^{-2}, from 215 to 370 g m^{-2}, and from 213 to 352 g m^{-2}, respectively, during the 15 month measurement period. Juvenile specific leaf weight was significantly lower ($P < 0.05$) than specific leaf weight of small adults and large adults during all measurement periods except January, April, and May 1988 (Miller et al. 1992).

From May to September, the combined elongation growth of all branchlet segments increased mean branchlet length of juveniles 2.8 ± 0.3 to 4.5 ± 0.8 times the initial measurements and of small adults 4.7 ± 0.8 to 6.9 ± 1.0 times (x ± 1 S.E. n = 12 for juveniles, and n = 11 for small adults). The most rapid branchlet elongation of juveniles occurred during May and June with slower growth in July. Branchlet elongation of small adults was most rapid in June and July. No additional branchlet elongation was measured for either juveniles or small adults after August first (Miller et al. 1992).

The response of juvenile and small-adult western juniper was measured relative to mid-April additions of 9 g N m^{-1} as calcium nitrate or 9 g N m^{-1} as ammonium + dicyandiamide (DCD) added as dry granules to a circular area three times the diameter of the projected tree crown area (Miller et al. 1991a). Both fertilizer treatments increased foliar nitrogen concentrations in juvenile and small adults in May relative to concentrations in the controls (n = 7) (Miller et al. 1991a). The highest concentrations 1.53 ± 0.06 were measured in small adult foliage from the nitrate-N treatment in July.

Nitrate-N and ammonium-N addition did not increase CO_2 assimilation in juvenile or small adult western juniper compared to rates measured in the controls (Miller et al. 1991a). Instead, both N-treatments reduced the magnitude of the measured July increase in CO_2 assimilation, relative to assimilation measured in May in each treatment, and increased the measured August-September depression of assimilation. The negative relationship between nitrogen addition and assimilation was more apparent in juveniles than in small adults; these negative effects were more pronounced in the ammonium-N treatment than in the nitrate-N treatment.

Water-use-efficiency was enhanced by reducing transpirational water loss rather than by increasing rates of CO_2 assimilation.

Mean branchlet elongation of juveniles and small adults was higher with both fertilizer treatments, but variability reduced significance levels. Depression of physiological process in juvenile western juniper from the ammonium-N treatment led to the conclusion that juveniles did not preferentially utilize ammonium-N, even though ammonium-N was the dominant form of nitrogen in soil at the research site (Miller et al 1991a). Western juniper appears to be adapted to utilize low, ambient levels of soil nitrate-N.

In early April, approximately 50% of the foliage was removed from lateral branches of juvenile and small-adult western juniper beginning with older foliage at the proximal end of the branch (cut-top treatment) (Miller et al. 1991b). Lateral roots were severed at the canopy edge to a depth of 36 cm (14.2 in) using a shovel (cut-root treatment). Roots were recut at the edge of the canopy three times during the summer to deter regrowth of severed laterals. Each treatment was replicated seven times.

Diurnal curves of CO_2 assimilation and leaf conductance were significantly higher for cut-top juveniles than for control juveniles during the April-May measurement period and for cut-top small adults during August (Miller et al. 1991b). Compared to the controls, the cut-root treatment significantly reduced diurnal curves of assimilation and leaf conductance in both juveniles and small adults during all three measurement periods.

Water-use-efficiency (WUE; CO_2 assimilation in μmol g^{-1} s^{-1}/transpiration in μmol g^{-1} s^{-1}) in April-May was not affected by either the cut-top or the cut-root treatment. During July, diurnal WUE curves of cut-top small adults and cut-root juveniles and small-adults were lower than those of the controls. By August, diurnal curves of WUE of cut-top juveniles and small adults were similar to controls, but curves of cut-root juveniles and small adults were still significantly lower than those of the controls.

Only in July were midday xylem pressure potentials of cut-top small adult and cut-root juvenile and small-adult western juniper significantly more negative than those of the controls. By August, midday xylem pressure potentials were -5.5 MPa and -6.5 MPa in control and cut-root juveniles, respectively, and only the cut-root small adults had more negative xylem pressure potentials than the controls.

Nitrogen concentrations in cut-top juvenile and small-adult western juniper were similar to controls during all measurement periods. The cut-root treatment reduced nitrogen concentrations in both juvenile and small-adult foliage in July and September ($P < 0.03$-<0.001). Lateral roots that extend beyond the canopy may be more important for nitrogen acquisition than for the uptake of other macro- and micro-nutrient elements which were adequately supplied by the remaining root systems.

During the period from May 3 to September 7-8, mean branchlet elongation of juveniles and small adults was similar in the cut-top and control treatments but was significantly reduced in the cut-root treatment.

By August, physiological processes of cut-top juvenile and small-adult western juniper were similar to those of the controls indicating that an overall metabolic control was functioning to regulate the balance between CO_2 assimilation and water loss. However, by August this balance had not been reached in the cut-root treatment.

Data from this research indicates that loss of foliage in western juniper trees through disease or herbivory, whether by insects or large ungulates, is likely to have a small impact on individual plants but that lateral root loss through disease agents or through belowground herbivory is likely to have a significant impact on tree health and survival under stress. Management practices that reduce foliage area of juvenile and small-adult western juniper, without killing the trees, would be less detrimental than practices that disturb the lateral root system, which extends beyond the crown of individual trees.

Over all, physiological responses for juvenile western juniper in eastern Oregon were more responsive to environmental conditions than were similar processes for adult trees. Carbon dioxide assimilation of juveniles varied 71% more with the measured range of photosynthetic photon flux density and 74% more with the measured range of leaf temperatures than did assimilation for large adults. Leaf conductance for juveniles was 39% and 26% more variable with the measured range of vapor pressure deficits and xylem pressure potentials than was conductance of adults (Miller et al. 1993).

Stomata of adult foliage did not appear to have the same feed forward response to vapor pressure deficits as was measured in juvenile foliage. Location of adult leaf stomata on the adaxial surface, not exposed to air movement, and on the abaxial surface, covered by the adjacent scale leaf (Miller and Shultz 1987), may reduce the sensitivity of the response of adult leaf conductance to high vapor pressure deficits (Miller et al. 1993).

The more extensive root system of adult western juniper was better able to keep up with the evaporative demand when vapor pressure deficits were high. Signals from the smaller juvenile root system may have triggered cyclical stomatal closure to more closely balance supply and demand of soil moisture.

Although stomata of juvenile western juniper were more responsive than adult stomata to vapor pressure deficits and xylem pressure potentials, juveniles did not restrict transpiration when vapor pressure deficits were high. Assimilation rates of juveniles were not high enough to compensate for their high transpiration. Therefore, adult western juniper with less responsive stomata and lower rates of assimilation had higher water-use-efficiencies when soil moisture and vapor pressure deficits were high than did juveniles (Miller et al. 1993).

Established adult western juniper are more buffered against variations of soil moisture than are juveniles. The responsiveness of juveniles to soil moisture is advantageous under favorable conditions. However, the depression of juvenile CO_2 assimilation and the relative inability of their stomata to restrict water loss when soil water reserves are limited may reduce their establishment, competitive ability, and the spread of western juniper in eastern Oregon during periods of reduce precipitation (Miller et al. 1993). These responses may also explain the preponderance of establishment beneath sagebrush or other shrubs.

Western juniper with 100% awl-like juvenile foliage can be as tall as small adults with scale-like foliage; therefore, tree height does not seem to determine foliage type. The phase change for western juniper from juvenile to adult foliage appears to be a reaction to stimuli that arise in the external environment or in other parts of the plant rather than a response of the meristem to the attainment of some critical plant size. The change for juvenile awl-like to adult scale leaves may indicate reduced cell elongation in response to increased water deficits. However, the associated changes in nitrogen concentrations, rates of CO_2 assimilation, and potential photosynthetic nitrogen-use efficiency may be in response to genetic activity, increased allocations to anti-herbivore compounds, or reduced resource availability (Miller et al. in press).

The advantages in increased CO_2 assimilation that a larger tree would accrue by retaining juvenile foliage would be offset by the increased transpirational water loss for juvenile foliage compared to adult foliage. In semi-arid areas currently occupied by western juniper, soil moisture reserves probably could not support the additional 40% water lost through transpiration if juvenile foliage were retained as individuals grew to be large trees (Miller et al. in press).

The suite of physiological processes associated with juvenile awl-like foliage should enhance establishment and early growth of western juniper in western rangeland and increase its competitiveness. Compared to small adults, juveniles had greater allocations to foliage and fine root biomass, higher rates of CO_2 assimilation, leaf conductance, and transpiration, and lower investments of biomass and nitrogen per unit of foliage. The transition to adult foliage is not a consequence of the high cost of producing juvenile foliage; juvenile foliage is less costly to produce than is adult foliage. Rather, the transition to adult foliage appears to be because physiological processes that are advantageous for foliage of a small tree become disadvantageous for a larger tree. Once established, the transition to a more conservative use of resources associated with adult scale-like foliage is consistent with the stress tolerant strategy of long-lived evergreen trees (Miller et al. in press).

Western Juniper — Measured and simulated leaf conductance and transpiration

Research on leaf conductance and transpiration was conducted at the Northern Great Basin Experimental Range, southeastern Oregon (Miller and Shultz 1987). Soil textures ranged from loam near the surface to gravelly loam at lower depths and were underlain by columnar basalt bedrock at about 112 cm (44 in). The 40-year mean annual precipitation for the area is approximately 300 mm (12 in). The majority of the moisture is in the form of snowfall between September and June. The site is a mountain big sagebrush/Idaho fescue habitat type (Winward 1970) at 1,360 m (4,462 ft) elevation.

Xylem water potentials and leaf conductance were measured on one branch from each of six large adult western juniper trees from September 1982 through October 1984. Transpiration was calculated from measurements of leaf conductance and vapor pressure deficit made on two branches on the north and south aspects of each tree. Osmotic potentials at full and zero turgor were measured. Precipitation, air and soil temperatures, relative humidity, vapor pressure deficits, photosynthetically active radiation, and soil water content were measured concomitantly (Miller and Shultz 1987).

Precipitation was 115% to 150% of normal during the measurement period. There was no difference in leaf conductance on the north and south sides of trees, so results were averaged. The most negative midday xylem pressure potentials, -2.7 MPa, were measured in September, 1983. Midday xylem pressure potentials were significantly correlated with vapor pressure deficits ($r = -0.63$, $P < 0.10$) and with transpiration ($r = -0.72$, $P < 0.10$). Midday leaf conductance ranged from 0.02 to 0.13 cm s^{-1} (SD = 0.004 and 0.016) over the two-year period. Transpiration ranged from 0.04 $\mu g\ cm^{-2}\ s^{-1}$ in winter to 2.0 $\mu g\ cm^{-2}\ s^{-1}$ in May and June. Osmotic potential at full turgor ranged from -1.8 to -2.0 MPa (SD = 0.166 and 0.163); osmotic potential at zero turgor was -2.4 to -4.2 MPa (SD = 0.131 and 0.306) (Miller and Shultz 1984).

No single factor influences leaf conductance of adult western juniper; conductance was influenced by soil moisture, evaporative demands, and soil temperature. Soil temperatures below 10°C in the root zone appeared to limit water movement into and through the tree, reducing xylem pressure potentials and leaf conductance (Miller and Shultz 1984).

Western Juniper — Modeling Leaf Conductance and Transpiration

Water relations data collected by Miller and Shultz (1987) were used to develop a model of leaf conductance and transpiration for adult western juniper (Angell and Miller 1994).

The leaf conductance model for western juniper (JUCO) was written in Microsoft FORTRAN Version 5.0 and runs on an 80386-based computer. Precipitation, (mm), diurnal temperature extremes (°C), and daily solar radiation ($cal*cm^{-1}*d^{-1}$) are daily input variables. JUCO simulates leaf conductance for a moderate density (up to 150 trees/ha, 61/ac) even-aged stand of western juniper in the northern Great Basin Transpiration is calculated based on leaf conductance and vapor density deficit. Stomatal conductance is based on current soil temperature at 10 cm (4 in) depth, soil water pressure in the wettest soil layer, and the overnight minimum temperature. Stomatal conductance is set to the maximum potential rate at sunrise and declines during the day. Stand transpiration is estimated at the end of the day and reported in mm water. At the end of the day, soil water is uniformly removed from the soil profile. Daily soil water balance is maintained by coupling JUCO with the field scale version of the upland hydrology component of SPUR (Simulation of Production and Utilization of Rangelands) (Renard et al. 1987).

The model was calibrated with the 1983 data set on western juniper leaf conductance and tested against measured leaf conductance data from 1984 (Miller and Shultz 1987). Simulated maximum potential leaf conductance approximated measured values well throughout the spring and summer 1984, differing from seasonal means by more than one SD on only three days. The model closely predicted transpiration except for one period in August when the model predicted stomatal closure which was not measured (Angell and Miller 1994). The model predicted that the western juniper stand transpired 47% of the total evapotranspiration of 300 mm during a wet year. Based on drought year simulation, even moderate density western juniper stands appear to have the potential for significant impact on site hydrologic processes (Angell and Miller 1994).

The model provides resource managers with a tool to assess the impact of developing western juniper woodlands on water use based on stand density, basal area, and environmental conditions. Further research is needed to compare model predictions with measured transpiration on widely differing sites, for different climatic condition, and for uneven-aged stands (Angell and Miller 1994).

Seasonal soil moisture depletion at 7.5 cm (3 in) depth was measured at various distances from the tree bole (n=10) in the study in northeastern California (Young and Evans 1984). Moisture depletion was measured from early spring through midsummer at four locations from the bole outward. Only at the margin of the tree canopy was herbaceous vegetation sufficient to influence soil moisture depletion. Soil moisture was depleted (-1.5 MPa) by early summer from the mid-point of the tree canopy radius out into the intercanopy area.

Jeppesen (1978) used fiberglass cells to determine soil moisture changes at 15 to 76 cm (6 - 30 in) depth in a central Oregon woodland study. Soils were deep, fine loamy to sandy loam texture, with a pH of 7.8 near the surface and 8.6 below 76 cm (30 in). At one site, soil moisture ranged from near field capacity to the permanent wilting point at 51 cm (20 in) between December 15 and January 15. The soil surface was frozen and all understory plants were dormant leading to the conclusion that western juniper used the moisture during this period. A second woodland site showed less extremes in soil moisture. In contrast on a thinned woodland site, soil moisture recharge took place during December and high amounts of soil water were present through the summer.

Eddleman and Miller (1992) estimated the potential water intercepted and transpired from two western juniper stands in central Oregon. Detailed physical measurements were made for the woodland and for year-long precipitation events. One stand had 440 trees/ha (178/ac), 22% canopy cover and an estimated 2,885 kg/ha (2,576 lbs/ac) of foliage. The second had 1,245 trees/ha (504/ac), 39% canopy cover, and an estimated 4,920 kg/ha (4,394 lb/ac) of foliage. Soil moisture was estimated to be available, although limited, in July for the first stand. For stand 2 only low amounts of soil moisture were estimated to be present in any fall, winter or spring month and it was low in June and essentially absent thereafter. Western juniper in closed stands appears potentially capable of intercepting and using most of the moisture that falls, but other plants take advantage of surplus moisture when it is present during their growth period.

Gray Rabbitbrush

Gray rabbitbrush (*Chrysothamnus nauseosus*) is widespread through western juniper woodlands, with abundance related primarily to degree of disturbance and time since disturbance. It generally reaches highest densities in early to mid seral communities, but may be absent from well developed young western juniper woodlands. Any activity in western juniper woodlands which results in high levels of surface soil disturbance can potentially increase gray rabbitbrush. This plant usually crown sprouts when burned, increases seed production following disturbance, disperses its seed by wind and with the exception of a few subspecies, foliage and twigs are little consumed by herbivores. The above attributes of gray rabbitbrush make it a significant transitional contributor to many site processes. Data on the physiological ecology of gray rabbitbrush are not available from western juniper woodland communities; however, data are available for gray rabbitbrush (Gray) from Utah (Donovan and Ehleringer 1991, 1992, Donovan et al. 1993).

The research site was the Range Experimental Field Station at Tintic, Utah (39°55'N, 122°03'W, elevation 1775 m). Soils at the site are sandy loams (Jensen 1983). The area receives an average of 374 mm precipitation per year, 75% of which occurs from October through May, predominately as snow. The site was dominated by Utah juniper and big sagebrush until the early 1950s when it was cleared and plowed. Since then, the site has recovered and it is now occupied by the sagebrush steppe vegetation type (West 1988).

Additional data were collected at the Red Butte Canyon Research Natural Area, 1.5 km east of the Univ. of Utah, Salt Lake City, UT. which receives 580 mm (22.8 in) of precipitation annually, one-fourth occurring in summer. At Red Butte, gray rabbitbrush were sampled at two locations, a riparian habitat along a stream at 1,630 m (5,348 ft) elevation and on an adjacent scrub oak, xeric hillslope 300 m (984 ft) away.

Diurnal courses of stomatal conductance and net photosynthesis were measured on intact branches. Xylem pressure potentials, leaf area, stomatal conductance, and leaf carbon and nitrogen concentrations were measured.

Greenhouse studies used the Tintic population as a seed source. Seedlings were grown at various densities in 15 cm (6 in) diameter PVC (polyvinyl chloride) pots with heights ranging 31 cm (12 in) to 1 m (39 in) tall.

During June maximum rates of CO_2 assimilation, leaf conductance, and transpiration occurred at mid-morning (Table 7) (Donovan and Ehleringer 1992). Juvenile gray rabbitbrush had significantly higher rates than large adults. Juveniles were operating at higher internal concentrations of CO_2 and had lower CO_2 assimilation/transpiration ratios than did large adults. Juveniles had more negative pre-dawn and mid-day xylem pressure potentials. The Δ-values for individuals within the population ranged from 16.9 to 24.7 0/00. Plant size and Δ-values exhibited a significant negative correlation. The smaller plants were less water-use efficient and operated at higher internal CO_2 concentrations than did large adults.

Juvenile leaves had lower nitrogen content and lower potential photosynthetic nitrogen-use efficiencies (PPNUE) than did large adults (Table 7) (Donovan and Ehleringer

1992). Juvenile leaves were significantly shorter than those of large adults (3.0 ± 0.7 cm vs. 4.1 ± 0.6 cm). Leaf specific weight was not significantly different

Table 7. Comparison of Juvenile and large adults classes of *Chrysothamnus nauseosus* for the Tintic, Utah, population, June 1989, presented as mean ± SD: pre-dawn xylem pressure potential (ψ_{pd}), midday xylem pressure potential (ψ_{md}), photosynthesis (A_{max}), stomatal conductance to water vapour (g_{max}), instantaneous ratio of internal to ambient CO_2 concentration (c_i/c_a), transpiration (E), instantaneous A/E, carbon isotope discrimination (Δ), integrated c_i/c_a estimated from Δ, integrated A/E estimated from Δ and the leaf-to-air vapour pressure deficit, leaf nitrogen, potential photosynthetic nitrogen use efficiency (PPNUE), and plant height. All differences between juvenile and large adult classes were significantly different ($P<0.05$) based on a two-tailed Student's t-test comparison of juveniles and adults, with the exception of the instantaneous c_i/c_a which was based on a one-tailed Student's t-test since the direction of the difference was predicted. Sample sizes ranged from 18 to 20 for the juvenile class, and from 19 to 20 for the large adult class.

	Juveniles	**Large Adults**
ψ_{pd} (MPa)	-0.86 ± 0.23	-0.63 ± 0.09
ψ_{md} (MPa)	-1.72 ± 0.20	-1.60 ± 0.16
A_{max} (μmol m^{-2} s^{-1})	21.5 ± 3.0	19.2 ± 3.7
g_{max} (mol m^{-2} s^{-1})	0.32 ± 0.08	0.26 ± 0.08
Instantaneous c_i/c_a	0.68 ± 0.06	0.64 ± 0.08
E (μmol m^{-2} s^{-1})	6.91 ± 2.25	4.77 ± 1.22
Instantaneous A/E (μmol mol^{-1})	3.30 ± 0.73	4.31 ± 1.22
Δ (°/∞)	19.88 ± 0.73	18.48 ± 1.02
Integrated c_i/c_a	0.69 ± 0.03	0.63 ± 0.05
Integrated A/E (mmol mol^{-1})	3.16 ± 0.67	4.46 ± 0.95
Leaf nitrogen (mmol g^{-1})	1.53 ± 0.12	1.86 ± 0.21
PPNUE (mmol mol^{-1})	86.8 ± 17.5	58.3 ± 13.1
Plant height (m)	0.21 ± 0.07	1.24 ± 0.07

(from Donovan and Ehleringer 1992).

between size classes (168 ±27 and 182 ± 33 g m^{-2} for juveniles and large adults, respectively). Adults supported far more leaf area than juveniles and transpired more water overall on a per plant basis, but less water per unit leaf area.

At the Red Butte Canyon dry location, CO_2 assimilation of juvenile gray rabbitbrush was lower (~9.8 μmol m^{-2} s^{-1}) than that of reproductive adults (~18 μmol m^{-2} s^{-1}); assimilation was higher, but similar for the two size classes at the wet location (~21 and ~17 μmol m^{-2} s^{-1}) (Donovan and Ehleringer 1991). Stomatal conductance was the reverse, similar for juveniles and adults at the dry location (0.22 and 0.3 mol m^{-2} s^{-1}, respectively) and different at the wet site (~0.68 and 0.44 mol m^{-2} s^{-1}, respectively).

Juvenile gray rabbitbrush that survived the summer drought had significantly higher Δ-values (21.04 ± 1.20, n = 21) than did non-surviving juveniles (20.01 ± 1.20, n= 23). The Δ-value for surviving juveniles was also significantly higher the Δ-value in reproductive plants (20.01 ±0.75, n = 10) (Donovan and Ehleringer 1991). Forty-seven percent of the juveniles died at the dry location; while 6% of the juveniles died at the wet location. None of the large reproductive adults died at either location (Donovan and Ehleringer 1991).

Green rabbitbrush

Green rabbitbrush (*Chrysothamnus viscidiflorus*) is a widespread component of western juniper woodlands. The species actively invades disturbed areas and may remain as scattered individuals in late seral and potential natural communities (PNC). Some subspecies are palatable to large ungulates and other subspecies are not. As in gray rabbitbrush, the species actively crown sprouts and is a producer of wind dispersed seed. Green rabbitbrush has the capability of influencing successional processes following disturbance in the western juniper woodland.

Limited data are available for green rabbitbrush (*Chrysothamnus viscidiflorus* ssp. *viscidiflorus* (Hook.) Nutt.) at the Northern Great Basin Experimental Range in southeastern Oregon (Miller 1988).

Soils at the location of this research vary in depth from 40 to 50 cm (16 to 20 in), and are underlain by a indurated duripan 5 to 20 cm (2 to 8 in) thick. The vegetation was a Wyoming big sagebrush-Thurber's needlegrass habitat type.

Leaf conductance and xylem pressure potentials were measured on six plants at nine dates during the summer of 1985 and at seven dates during 1986. Measurements were made in the early morning (0400 and 0800 h) and at midday (1400 h). Transpiration was calculated from conductance measurements and simultaneous measurements of vapor pressure deficits. Phenology and leaf area index were also measured on five plants.

Spring growth of green rabbitbrush began during the second week of April; leaf expansion continued until early July; senescence of early spring leaves began in late

July (Miller 1988). The greatest leaf area index was measured on June 28 (0.7, SD = 0.114). Maximum early morning leaf conductances were ~ 0.9 cm s^{-1} in early June; midday maximum conductances were ~0.65 cm s^{-1} in both April and June. Midday transpiration was highest in late June ~14.5 μg cm^{-2} s^{-1}. Xylem pressure potentials at 0400 h declined from -0.5 MPa in April to ~-3MPa in late August. Midday xylem pressure potentials were ~-1.2 MPa in April declining to ~-4.3 MPa in late August. Soil moisture around individual plants declined through the summer from ~18% soil water at 2 to 20 cm (0.8 to 8 in) and ~22% at 20 to 40 cm (8 to 16 in) in April to ~5% at both depths in late August (Miller 1988).

Sandberg bluegrass

Sandberg bluegrass (*Poa sandbergii*) is an abundant perennial grass in the western juniper woodland. Both overgrazing and intense competition from western juniper trees may result in a shift in understory dominance by large tufted perennial grasses to a dominance by Sandberg bluegrass. This species is a small early growing bunchgrass. Its root system is relatively shallow and may form a mat just under the soil surface. This species, due to its abundance, its early growth, its low stature, and its shallow root mat plays an important role in successional and other system processes in western juniper woodlands.

Data are not available on the physiological ecology of Sandberg bluegrass growing in western juniper woodlands. However limited data is available for Sandberg bluegrass from a grass community in southeastern Washington (Link et al. 1990).

The research site was located on the U.S. Department of Energy's Hanford Site in southeastern Washington, on the Columbian Plateau. The annual precipitation is 160 mm (6.3 in). The current vegetation is composed of 30% canopy cover of Sandberg bluegrass and 20% cheatgrass. Spring draba (*Draba verna*) and salsify (*Tragopogon dubious*) are also present in the community (Link et al. 1990).

Stomatal conductance, transpiration, and soil moisture were measured on three dates in April and May 1986 (Link et al. 1990). Phenology and xylem pressure potentials were also measured. In 1987, measurements were made on irrigated and non-irrigated plants at the same site.

Mean maximum stomatal conductance and predawn xylem pressure potentials of Sandberg bluegrass were 0.54 cm/s and -0.16 MPa on April 11 and declined to 0.10 cm/s and -3.4 MPa by May 1 (Link et al. 1990). The highest rates of transpiration were measured on April 11, ~4 μg/cm^2/s. Root/shoot ratio of oven dried live roots and green shoots was about 2. Roots of Sandberg bluegrass extended to a depth of 35 cm (14 in). The majority of the root mass was found in the top 10 cm (4 in) of the soil and few roots occurred below 20 cm (8 in). On non-irrigated plots, total senescence occurred by late May; irrigation delayed senescence until June 9th. Irrigation delayed senescence, but did not prevent it. Other factors that drive phenological development in addition to soil water availability also contribute to the development of water stress (Link et al. 1990)

Idaho fescue

Idaho fescue (*Festuca idahoensis*) is a frequent dominant of understory herbaceous vegetation in western juniper woodlands. This perennial mid-sized bunchgrass, though common in many PNCs, declines in abundance with overgrazing but frequently survives under situations of disturbance and stress beneath the canopy of western juniper trees.

Research on the physiological ecology of Idaho fescue has focused on seed germination (Doescher et al. 1985) and seedling growth (Nasri and Doescher in press a, b, Goodwin 1993). Germination trials were conducted on Idaho fescue seeds collected from four eastern Oregon locations ranging in elevation from 1,350 to 1,750 m (4,429 to 5,642 ft) (Doescher et al. 1985). Surface soils were loams to sandy loams. Seeds of Idaho fescue for seedling growth studies were collected from five sites near Prineville, Oregon (44°15'N, 120°45'W) and grown in soil collected from one of the sites, Combs Flat (Nasri and Doescher in press a, b, Goodwin 1993). The response of Idaho fescue growth to temperature and competition with cheatgrass was measured in greenhouses and growth chambers at variable temperatures (Nasri and Doescher in press a, b).

Maximum germination rates occurred between 20-25°C; no seeds germinated at 35°C, but 47-82% of the seeds germinated at 5°C (Doescher et al. 1985).

Idaho fescue seedlings from undisturbed and disturbed (hand scarified) sites had 52% and 42% of their roots in the upper 0 to 2 cm (0 to 0.8 in) of the soil column, respectively (Goodwin 1993). Both groups had 60% of their root biomass in the upper 10 cm (4 in) of the soil. Disturbed site plants produced only 40% as much root length as seedlings from the undisturbed site, but specific leaf areas, specific root lengths, root weight, and root length:leaf area ratios were similar for plants from all sites. Idaho fescue from the undisturbed site competed with cheatgrass for resources more successfully than did the disturbed site populations of Idaho fescue (Goodwin 1993).

After nine weeks the total root length and belowground biomass of Idaho fescue grown at 5, 10, and 15°C was 101 cm (40 in) and 8 mg, 2,418 cm (952 in) and 622 mg, and 3,800 cm (1,496 in) and 1,145 mg, respectively. Aboveground biomass ranged from 10 - 23 mg at 5°C, 544 - 1,177 mg at 10°C, and 591- 1,111 at 15°C. Idaho fescue produced 3 tillers when grown at 5°C, 52 at 10°C, and 62 at 15°C (Nasri and Doescher in press a). When grown alone Idaho fescue produced 0.27 - 0.57 g plant^{-1}, whereas with 10 cheatgrass plants the dry mass of individual Idaho fescue ranged from 0.20 - 0.25 g plant^{-1} (Nasri and Doescher in press b).

Ecology of Western Juniper Woodlands

Geology and Soils

Western juniper is found on soils developed from a broad range of parent materials of sedimentary, igneous and metamorphic origin including rhyolite, andesite, basalt, dacite, saprolite, tuff and tuff breccias, igneous and pumice sands, as well as alluvial, colluvial, lacustrine and aeolian mixtures of the above (Burkhardt and Tisdale 1969, Dealy et al. 1978a, Driscoll 1964a and 1964b, Eckert 1957, Pomerening et al. 1983, Vaitkus and Eddleman 1991, Young and Evans 1981).

Driscoll (1964a) classified western juniper woodlands in Oregon into three broad physiographic divisions based on soil parent materials:

1) Soils derived from aeolian igneous and pumice sands or for which these sands are mixed through the soil horizons. These soils form a fairly continuous band from southern Wasco County south into northern Deschutes County and eastward including western Crook County and most of Jefferson County. This same division occurs as large dispersed units in southern Deschutes and northwest Lake Counties.

2) Soils derived from old John Day and Clarno sedimentary formations occur 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.

3) Soils derived from igneous materials are found in southern Wasco County, Sherman and Wheeler Counties, and on the North Fork of the John Day River in Grant County. In addition juniper found on the Owyhee Plateau in Idaho as well as those in Malheur, Harney, southern Klamath and northwestern and southern Lake Counties in Oregon and northern Modoc County in California are on these soils (Baldwin 1981).

These divisions carry broadly differing land management implications relative to watershed function and sustainable productivity and for the present, these divisions should be maintained and refined.

Western juniper is present on all exposures and slopes. It grows well on level and undulating topography, toe slopes, alluvial fans and terrace benches, steep slopes and scattered through rocklands and rocky scarps. Old woodlands are generally found on mesa edges, ridges and knolls where fractured bedrock is near the surface. Soils range from 0 to several feet deep where 0 is bare but fractured rock outcrop (Burkhardt and Tisdale 1969). Young woodlands are generally found on valley slopes and bottoms with few rock outcrops. Soils of young woodlands are rather uniform and much deeper than soils of old woodland (Burkhardt and Tisdale 1969) and many contain claypans (Pomerening et al. 1983).

In general little information exists which correlates soils with western juniper populations and productivity. Published soil surveys such as those for central and eastern Oregon (Dyksterhuis 1981, Green 1975, Lentz and Simonson 1986, Pomerening et al. 1983) indicate only general occurrence of juniper and occasional reference is made to the presence of old growth trees. Other studies (Burkhardt and Tisdale 1969, Driscoll 1964a, 1964b, Eckert 1957, Erhard 1980) describe the soils for several plant communities or associations that contain western juniper, while Burkhardt and Tisdale (1976) attempted to correlate western juniper seedling density and growth to various soil and site factors.

Soils classed as Haplaquolls, Cryoborolls, Argixerolls, Durixerolls, and Haploxerolls (Mollisols) and Durargids and Camborthids (Aridisols) appear to support high densities of western juniper. Durargids, Haplargids, and Camborthids (Aridisols); Chromoxererts (Vertisol), and some Argixerolls (Mollisol) soils support at least scattered junipers (Driscoll 1964a, 1964b; Green 1975; Dyksterhuis 1981; Josaitis 1991; Lentz and Simonson 1986; Pomerening et al. 1983). Both mesic and frigid temperature regimes are common for western juniper and although the mesic condition tends to dominate it may do so as a consequence of the geographic locations of completed studies and surveys.

The very plastic adaptation of western juniper to parent materials and soil types means that the woodland occurs on a very broad group of soil series. For example, soil series in eastern Oregon on which various ages and densities of juniper exist include Agency, Ayres, Bakeoven, Balder, Beden, Bieber, Coptie, Courtrock, Day, Decantel, Degner, Deschutes, Dilanson, Donnybrook, Elmore, Fopiano, Gardone, Houstake, Ginser, Grell, Gribble, Gwin, Lamonta, Lickskillet, Lithgow, Logdell, Lookout, Lorella, Madeline, McCoin, McMeen, Meld, Metolius, Milican, Ninemile, Ochoco, Polly, Prag, Prineville, Redcliff, Redmond, Searles, Slayton, Simas, Simaton, Snell, Sorf, Statz, Stookmoor, Tub, Ukiah, Ventor, and Waterbury (Soil surveys by Dyksterhuis 1981, Green 1975, Lentz and Simonson 1986, Mayko and Smith 1966, Pomerening et al. 1983). Juniper is not necessarily present on all the area of any one soil series. Within a few series certain slopes and phases contain little or no juniper.

The large number of soil series on which western juniper may occur suggests that issues relative to management of woodlands, such as sustainable productivity, growth rates, tree densities, and understory vegetation and soil response will more properly rely on surveys at the phase level. Aspects of juniper establishment and growth relative to soil chemistry, texture horizonation and depth are not well understood at present. Further research into soil calcium and texture may be helpful in understanding juniper ecology and management. For example Anderson (1956) concluded that the widespread expansion of western juniper, on certain soils in Oregon, indicates its affinity for highly calcareous fine texture soils derived from sedimentary deposits. Soil studies indicate that some western juniper soils are high in calcium (Table 8). Physiological studies (see section on physiological ecology) show high levels of calcium in the plant's tissue (Miller 1990), while Burkhardt and Tisdale (1976) found fine textured soils favorable for juniper seedling growth.

In addition to the above soil surveys Burkhardt and Tisdale (1969) in southeastern Idaho, Driscoll (1964a, 1964b) in central Oregon, and Dealy et al. (1978a) in central Oregon, and Josaitis (1993) in southeastern Idaho provide the following general information on soils within juniper woodlands.

Soil profile development is often weak and quite variable between soils. Soil depth ranges from very shallow, 30 cm (12 in) interspersed with rock outcrops to very deep, 152 cm (60 in). Shallow soils tend to be very stony, cobbly or gravelly while deep soils tend to have stony, cobbly or gravelly layers somewhere in the profile. Soils less than 60 cm (24 in) are usually underlain by unweathered or weathered bedrock.

Sandy loams, loams, clay loams, silt loams and silty clay loams are common textures of the upper horizons. Within 10 - 25 cm (4 - 10 in) of the soil surface, clay and clay loam textures appear tend to dominate the lower horizons in most soils.

Burkhardt and Tisdale (1969) found old woodlands had an interspace soil surface covered with considerable gravel pavement and a high rock content in the profile while young woodlands had an interspace soil surface covered with vegetation and litter and little gravel pavement and low amounts of rock in the profile.

Specific studies on soils and soil-plant relationships are not numerous. Table 8 provides some of what is known about western juniper woodlands and their associated physical and chemical characteristics.

Mature juniper climax stands in southwestern Idaho had soil bulk densities that ranged from 1.43 to 1.69 while young aeral stands range from 1.23 to 1.68 (Burkhardt and Tisdale 1969). Lower bulk densities, mostly 1.00 to 1.10, were found by Eckert (1957) for soils associated with western juniper in northeastern Lake County and northwestern Harney County.

Soil pH in the surface horizon varies between 6.0 and 6.5. It may or may not increase with depth, however Driscoll (1964a) reported pH values as high as 8.0 for lower horizons in the profile. There appears to be a slight increase in pH beneath the tree canopies with highest pH values under older trees.

Soil organic matter is low with values of 2% or less common for the interspace surface horizon especially on sites at the drier end of the juniper zone. However for those studies or communities where Idaho fescue was prominent in the understory, organic matter content ranged from 3.4 to 6.8%. Organic matter decreases with soil depth but may increase under the canopy as trees age. Nevertheless where understory vegetation is in good condition, especially with high cover of Idaho fescue, and at the moist end of the zone intercanopy soils can be quite high in organic matter (Doescher et al. 1987 young woodlands in central Oregon) .

Cation Exchange Capacity ranges from 12 to 30 meq/100 g. No clear trends are apparent with the exception of a higher CEC beneath the canopy than in the intercanopy area. Calcium dominates the extractable bases, and generally decreases with depth and increases with tree age within the canopy zone.

Available phosphorus appears to decrease with soil depth and with soil disturbance. Neither tree presence nor tree age appear to influence P distribution.

Total nitrogen levels reported range from 0.06 to 0.43% and generally follow a moisture gradient being least with those sites where bluebunch wheatgrass dominates the herbaceous layer and greatest on those sites where Idaho fescue dominates. Evans and Young (1984) found considerable year-to-year difference in surface soil nitrogen in northeastern California. In one year nitrogen increased with proximity to the bole but not in the following year. Josaitis (1991) found total nitrogen in the canopy zone was associated with tree age.

Soil nitrate nitrogen has been shown to increase with proximity to the bole (Josaitis 1991, Young and Evans 1984); however, the magnitude of difference may change with sample date (Young and Evans 1984).

Temporal measurements of mineralizable nitrogen should be a better measure of microbiotic activity since it best represents potential plant available nitrogen, though no published values are available for the western juniper woodland.

It is unclear from the literature whether the greater amounts of nutrients associated with the juniper canopy zone as the tree ages represent (1) a spatial redistribution of nutrients from trees mining the intercanopy zone, or (2) an overall increase in nutrients for the site due to trees acquiring nutrients from previously unexplored portions of the solum or (3) a reduced nutrient losses from the site due to the presence of trees, or (4) a capture of nutrients in air borne dust by the canopy or (5) an efficient retention and incorporation of tree produced organic matter, or (6) certain combinations of the above.

It seems fairly clear from the literature that the presence of old western juniper trees often gives the woodland system a higher level and degree of nutrient patchiness than associated or previously existing sagebrush ecosystems. What is not clear is how much of this nutrient patchiness is due to the inherent aridity and moisture supplying capacity of the site and how much is due to environmental modification by the woodland trees. Deeper soils at the moist end of the woodland spectrum which are and have been for many years in good condition, probably with Idaho fescue dominating the herbaceous understory, may show a great deal less patchiness. However in the latter situation should the understory deteriorate due to high tree cover, protracted drought, or improper grazing then patchiness may follow.

Some of these questions may be cleared up by a western juniper study yet to be published. Tiedemann and Klemmedson (in press) used a bioassay approach to determine availability of nutrients from canopy and intercanopy soils from five age classes of trees. This study was made in the central Oregon pumice zone and results may not apply to other soils.

They found the availability of some nutrients were affected by tree age and that there may be a significant transport of some nutrients from the intercanopy soils to the canopy soils. They found both locations to be deficient in available nitrogen and similar to soils with no juniper invasion in the same area. Their results indicate a redistribution of nutrients in the root zone pool into large patches.

Soil variably influences growth rate, establishment rate and perhaps to some degree final density of western juniper but the influence of soil in all of these areas, though important, may be less than that of other ecosystem parameters such as climate, fire, grazing and the biology of the tree species.

Woodland studies are lacking on soils in low sagebrush and basin big sagebrush types and studies on soils derived from sedimentary materials. Published soils information gives a general idea of where western juniper can grow but information is lacking on the influence soil exerts on long-term growth and development of stands of juniper.

Climate

Detailed studies on the climate of the western juniper woodlands are not available. In general the western juniper woodland zone is the most zeric of the tree-dominated zones of the Pacific Northwest (Franklin and Dryness 1973). Dealy et al. (1978a, 1978b), and Dealy (1990) characterize the climate as mainly continental with Pacific marine air intrusions. The climate is typically semiarid with dry hot summers, cold winters, and precipitation ranging from 250 to 355 mm (9 to 14 in). Precipitation can vary from 230 to over 510 mm (9 to 20 in). Precipitation comes mostly as winter snow and as fall and spring rains. Peak precipitation months tend to be November-January and May-June periods. Months of July, August, and September are particularly dry.

Woodland Maturity

Western juniper stands are classified into two age groups, those which contain a strong old tree component and those which have only young trees present. Old woodland communities have been otherwise classified as climax, mature or ancient. Trees which dominate these latter stands are generally over 150 years old and may reach up to nearly 900 years of age (Holmes et al. 1975), however they also contain a variety of younger age classes. Within old woodlands, dying, dead, down, and decaying tree stumps are to be expected (Burkhardt and Tisdale 1969). Dominant trees in old woodlands are large, flat topped and heavy lower links. The abundance of *Letharia vulpina*, a bright yellow-green arboreal fruticose lichen, growing on the dead and dying wood of older trees and the abundance of *Tortula ruralis*, a moss, found primarily in the thick duff below old trees were noted as indicators of old woodlands by Burkhardt and Tisdale (1969).

Juniper canopy cover in old woodlands averaged 47% and ranged upward to 86%. They reported tree density to be directly related to the amount of fractured bedrock present in the study area and ranged up to 425/ha (172 ac) with an average of 237/ha

(96/ac). In their study young woodlands contained mature trees in the sense that they had nearly reached full height and appeared fully reproductive but as a woodland no old age classes are present and there was no evidence of dying, dead, down and decaying classes of individual trees, and little of the lichen and moss was present.

Young woodlands were dominated by trees less than 100 years old. These trees possess a strong terminal leader and conical shaped crowns (Burkhardt and Tisdale 1969). Juniper canopy cover averaged 22%, ranging upward to 46%, while tree density averaged 424/ha (172/ac), ranging up to 500/ha (202/ac), although the authors make reference to other samples with over 2000 adult trees/ha (809/ac). Density was reported to be related to stand development and age of trees on the invasion site.

Old woodlands tend to contain fewer understory plant species than young woodlands. Burkhardt and Tisdale (1969) found 2 shrubs, mountain big sagebrush *(Artemisia tridentata* ssp *vaseyana*) and bitterbrush *(Purshia tridentata*), 5 perennial and 1 annual grass species, 4 annual and 7 perennial forb species and 1 moss species in the old woodlands. Young woodlands contained an additional 2 shrub species, 2 perennial grass species, and 13 perennial forb species. However, as noted above, soils were much deeper and more uniform under young stands.

Burkhardt and Tisdale (1969) also found both squirreltail and Thurber's needlegrass to have high constancy and frequency in old woodlands but low values in young woodlands. Also, mountain big sagebrush and bitterbrush averaged 1% canopy cover each in old woodlands but 9% and 3% respectively in young woodlands.

General physiognomy of old woodlands was sparse vegetation cover and patchiness. Patch units consisted of (1) shrubs and herbaceous plants, (2) juniper trees, (3) rock outcrops, and (4) gravel pavement. The physiognomy of young stands was one of sagebrush-bunchgrass vegetation with juniper and reduced patchiness.

Plant Associations and Communities

Western juniper communities may be divided into three groups or zones: those which are inclusions in the forest zone (zone 1) , those which exist in the old juniper woodland zone (zone 2) , and young woodlands which in recent past have expanded into the sagebrush zone (zone 3). In zones 1 and 3, potential communities are expected to be very different from pre-settlement vegetation and since they appear to have not reached a stable state. The stable state character of these potential communities are unknown, rather the present communities appear in transition.

Groups 2 and 3 are not easily separated in the literature so that the classification below rests on combinations of topographic position, soil surface, and tree density given by the authors as a means of placement unless otherwise stated.

The following associations and communities have been described for western juniper woodlands (most of which have an n=6 or less):

1. *Juniperus occidentalis/Artemisia arbuscula/Poa sandbergii* Scabland (Zone 1 - Hall 1978b) Oregon, southern Blue Mountains and Fremont Nat. For., shallow stony soils, perched water table in the winter;

2. *Juniperus occidentalis/Artemisia rigida/Poa sandbergii* Scablands (Zone 1- Hall 1973, 1978) Oregon, Blue mountains, very shallow stony soil, water saturated soil in winter;

3. *Juniper occidentalis/Artemisia rigida* (Zone 1 - Johnson and Clausnitzer 1992) Central and southern Blue and Ochoco mountains, scablands and ponderosa pine forests (probably similar to #2);

4. *Juniperus occidentalis/Agropyron spicatum-Festuca idahoensis* (Zone 1- Hall 1978; Zone 2 - Driscoll 1964b) central Blue Mountains and Central Oregon, shallow stony to very stony soils, most slopes, 32% tree cover;

5. *Juniperus occidentalis/Festuca idahoensis-Agropyron spicatum* - (Zone 2, Hall 1973, Johnson and Simon 1987, Johnson and Clausnitzer 1992) Oregon, Wallowa-Snake Province, central and southern Blue and Ochoco mountains, upper slopes rock outcrops, tree cover 15-18%;

6. *Juniperus occidentalis/Artemisia tridentata/Festuca idahoensis-Lupinus* (Zone 2, Driscoll 1964b) Central Oregon, N to NE slopes, shallow stony soils, tree cover 12%;

7. *Juniperus occidentalis/Artemisia tridentata/Agropyron spicatum* (Zone 2, Eckert 1957, Driscoll 1964b, 1964b; Zone 3 - Hall 1973) Central Oregon, undulating uplands, 10% tree cover;

8. *Juniperus occidentalis/Artemisia tridentata* ssp. *vaseyana/Stipa occidentalis* (Zone 2 - Erhard 1979) Lava Beds Nat. Monument, California, pumice with basalt outcrops;

9. *Juniperus occidentalis/Artemisia tridentata* ssp. *vaseyana* (Zone 2 - Johnson and Clausnitzer 1992) Central and southern Blue and Ochoco mountains;

10. *Juniperus occidentalis/Purshia tridentata/Agropyron spicatum* (Zone 2 - Driscoll 1964a, 1964b; Volland 1976) Central Oregon, Deschutes and Fremont Nat. For., moderately -deep stony soil, southerly to all aspects, 3-30% tree cover;

11. *Juniperus occidentalis/Cercocarpus ledifolius/Carex geyer* (Zone 2 - Johnson and Clausnitzer 1992) Central and southern Blue and Ochoco mountains;

12. *Juniperus occidentalis/Cercocarpus ledifolius* (Zone 2 - Erhard 1979) Central and southern Blue and Ochoco mountains, Lava Beds Nat. Monument, California, cinder-pumice soils;

13. *Juniperus occidentalis/Artemisia arbuscula/Festuca idahoensis* (Zones 1, 2, 3 - Hopkins 1979) South central Oregon, Fremont Nat. For., extremely rocky surface soils, ridges and flat side slopes, 1-4 trees per acre;

14. *Juniperus occidentalis/Festuca idahoensis* (Zone 3 - Driscoll 1964a) Central Oregon, lower NW slopes, moderately deep soils;

15. *Juniperus occidentalis/Agropyron spicatum* (Zone 3- Driscoll 1964a; Erhard 1979) Central Oregon, Lava Beds Nat. Monument, California, moderately deep soils (OR) to shallow (CA), southerly to SW aspects, 43% tree cover;

16. *Juniperus occidentalis/Artemisia tridentata/Festuca idahoensis* (Zone 3 - Driscoll 1964b) Central Oregon, North facing slopes, deep soils, 12% tree cover;

17. *Juniperus occidentalis/Artemisia tridentata/Agropyron spicatum* (Zone 3 - Driscoll 1964b) Central Oregon, xeric southerly slopes, 28% tree cover;

18. *Juniperus occidentalis/Artemisia tridentata/Agropyron spicatum* (Zone 3 - Driscoll 1964a, 1964b) Central Oregon, northerly aspects, moderately deep soils, 46% tree cover;

19. *Juniperus occidentalis/Artemisia tridentata-Purshia tridentata* (Zone 3 - Driscoll 1964a) Central Oregon, deep none stony soils, 7% tree cover;

20. *Juniperus occidentalis/Purshia tridentata/Festuca idahoensis* (Zone 3 - Driscoll 1964a, Johnson and Clausnitzer 1992) Central Oregon, southern Blue and Ochoco mountains, southeast slopes, stony soils;

21. *Juniperus occidentalis/Artemisia arbuscula/Agropyron spicatum-Festuca idahoensis* (Zone 3 - Hall 1973, 1978b; Johnson and Clausnitzer 1992) Oregon, Southern Blue Mountains and Fremont Nat. For., shallow stony soils with a perched water table in the winter;

Western juniper also occurred on two big sagebrush associations and two low sagebrush associations described on the Northern Great Basin Experimental Range (Eckert 1957).

Range Sites

Site descriptions in use by the Soil Conservation Service (USDA Soil Conservation Service 1986-1990) for Oregon east of the Cascade Mountains show a very wide range of conditions under which western juniper is present and or has the potential to be present. These sites are separated into Major Land Resource Areas (MLRAs), Current and potential presence (potential invader) and into sagebrush groups.

Values in brackets are: total number of sites/number of western juniper dominated associations/juniper present or potentially present). A * indicates western juniper listed in the plant association name. The value to the left of the site, i.e. -1-, equals the number of sites with juniper present.

MLRA Cascade Mountains (Eastern Slope) B6(B)

(06/00/01)

*-1- Ponderosa pine (*Pinus ponderosa*) sites

MLRA- Palouse and Nez Perce Prairies B9

(25/00/02)

-2- Idaho fescue (*Festuca idahoensis*) sites.

MLRA Upper Snake River Lava Plains and Hills - B10

(65/00/30

-6- Basin Big Sagebrush sites (*Artemisia tridentata* ssp. *tridentata*);
-11- Mountain Big Sagebrush sites (*Artemisia tridentata* ssp *vaseyana*);
-1- Low Sagebrush sites (*Artemisia arbuscula*);
-2- Stiff sagebrush (*Artemisia rigida*) sites;
-3- Bluebunch wheatgrass (*Agropyron spicatum*) sites;
-2- Idaho fescue sites;
*-3- Mountain Mahogany (*Cercocarpus ledifolius*) site;
-1- Bitterbrush (*Purshia tridentata*) site;
*-1- Ponderosa pine (*Pinus ponderosa)* site.

MLRA Klamath and Shasta Valleys and Basins - D21

(25/00/14)

-1- Basin big sagebrush sites
-3- Mountain big sagebrush sites
-3- Low sagebrush sites
-4- Bitterbrush sites
-1- Mountain Mahogany sites
-1- Ponderosa pine sites
-1- Basin wildrye (*Elymus cinereus*) sites

MLRA - Malheur high plateau - D23

(27/00/13)

-1- Basin big sagebrush sites
-1- Threetip sagebrush (*Artemisia tripartita*) sites
-5- Mountain big sagebrush sites;
-2- Wyoming big sagebrush (*A.t.* ssp. *wyomingensis*) sites
-2- Low sagebrush sites;
-1- Bitterbrush sites
-1- Mountain mahogany sites

Note - of the sites listed in MLRAs B7 - Columbia Basin, B11 - Snake River Plains, D24 - Humboldt Area and D25 - Owyhee High Plateau, none contain reference to western juniper.

Mountain big sagebrush sites appear most often, 19 total, in the list of sites susceptible to western juniper expansion, followed by basin big sagebrush, 8 sites, with low sagebrush and bitterbrush each with 6 sites.

The literature all points to the very unsettled nature of developing western juniper woodlands. Researchers point to a few associations for which western juniper is present as old woodlands, however there is a vast area on which young woodlands are developing and another extended area which has the potential to develop into woodlands. As noted above, these young woodlands are in a state of transition in development of plant communities. Plant communities currently present are not likely to remain and future communities are at best difficult to predict.

Plant Species

The following is a list of vascular plant species commonly found in western juniper woodlands (Burkhardt and Tisdale 1969, Dealy 1978, Driscoll 1964a, 1964b, Rose 1989, Vaitkus 1986). This list includes species from a broad range of sites across the western juniper zones.

Trees
Juniperus occidentalis
  ssp. *occidentalis*
Pinus ponderosa

Shrubs
Artemisia arbuscula
Artemisia tridentata
  ssp. *tridentata*
  ssp. *wyomingensis*
  ssp. *vaseyana*
Artemisia rigida
Cercocarpus ledifolius
Chrysothamnus nauseosus
Chrysothamnus viscidiflorus
Grayia spinosa
Holodiscus dumosus
Purshia tridentata
Ribes cerium
Symphoricarpos oreophilus
Tetradymia canescens
Tetradymia glabrata

Sedges
Carex rossii
Carex geyeri
Kobresia simpliciuscula

Perennial Grasses
Agropyron saxicola
Agropyron smithii
Agropyron spicatum
Bromus carinatus
Danthonia unispicata
Elymus cinereus
Festuca idahoensis
Koeleria cristata
Oryzopsis hymenoides
Poa ampla (syn P. juncifolia)
Poa bulbosa
Poa compressa
Poa cusickii
Poa pratensis
Poa sandbergii
Sitanion hystrix
Stipa columbiana
  (syn. S. occidentalis)

Perennial Grasses (cont'd.)
Stipa comata
Stipa occidentalis
Stipa thurberiana

Annual Grasses
Agrostis interupta
Bromus brizaeformis
Bromus japonicus
Bromus mollis
Bromus tectorum
Festuca bromoides
Festuca mirostachys
Festuca octoflora
Taeniatherm asperum
  (syn. Elymus asperum)

Perennial Forbs
Achillea millefolium
Agroseris glauca
Agroseris 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 stenophylus
Balsamorhiza careyana
Balsamorhiza sagittata
Calcohortus macrocarpus
Castilleja applegatei
Castilleja chromosa
Chaenactis douglasii
Cheilanthes gracillima

Cirsium arvense
Crepis
Crepis acuminata
Crepis intermedia

Perennial Forbs (cont'd.)

Erigeron bloomeri
Erigeron elegantulus
Erigeron filifolius
Erigeron linearis
Erigeron poliospermus
Erigeron pumilus
Eriogonum heracleoides
Eriogonum microthecum
Eriogonum niveum
Eriogonum ovalifolium
Eriogonum spharocephalum
Eriogonum strictum
Eriogonum thymoides
Eriogonum umbellatum
Eriophyllum lanatum
Fritillaria pudica
Geum campanulatum
  (syn.: triflorum)
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
Phacelia hastata
Phlox douglasii
  (syn P. caespitosa)
Phlox hoodii
Phlox longifolia

Perennial Forbs (cont'd.)

Potentialla 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 Forbs

Alyssum desertorum
Amsimkia Intermedia
Blepharipappus scaber
Clarkia pulchella
Coldenia grandiflora
Collinsia parviflora
Collomia grandiflora
Cordylanthus ramosus
Cryptantha affinis
Cryptantha ambigua
Cryptantha ambigua
Descurainia pinnata
Descurania pinnata
Descurania richardsonii
Descurania richardsonii
Draba verna
Epilobium minutum
Epilobium paniculatum
Eriogonum vimineum
Eriophyllum lanatum
Erodium circutarium
Euphorbia spp.
Galium bifolium
Gayophytum humile

Gayophytum nuttallii
Hemizonia pungens
Holosteum umbellatum
Lactuca ludoviciana
Lagophylla ramoisissima
Layia glandulosa
Lepidium perfoliatum

Annual & Biennial Forbs (cont'd.)

Linanthus harknessi
Lupinus microcarpus
Madia gracilis
Madia sativa
Microsteris gracilis
Mimulus breweri
Montia perfoliata
Navarretia
Orthocarpus tenuifolius
Phacelia linearis

Annual & Biennial Forbs (cont'd.)

Plectritis macrocera
Polemonium micranthum
Polygonum majus
Ranunculus testiculatus
Ranunculus occidentalis
Sanguisorba minor
Sisymbrium altissimum
Taraxacum ceratophorum
Tragopogon dubius
Verbascum thapsus

Numerous deficiencies exist in the literature relative to understanding plant ecology in western juniper woodlands. Community level studies have not been carried out on either old or young woodlands on soils derived from sedimentary formations (physiographic division 2 Driscoll 1964a). No ecological studies have been reported for woodlands in Grant and Wheeler Counties in the north and Klamath, Lake, and Harney Counties in the southeast. These counties contain nearly 50% of the juniper woodlands in Oregon.

Although a potentially large gap in information exists, range site (US Department of Agriculture, Soil Conservation Service various dates) information for these areas provides a reliable base for initiation of management.

Given the history of use of present day western juniper woodlands, plant associations described for small ungrazed areas such as the "Island" at the confluence of the Deschutes and Crooked Rivers in northcentral Oregon, may have marginal applicability to western juniper woodlands as a whole. Also, plant associations determined from young woodlands in transition might misrepresent relatively stable stages yet to be reached, indicating the need for considerable long-term efforts to understand successional processes.

Not only is the list of plant species likely incomplete, the autecological and community level dynamics certainly are inadequate or absent for large numbers of plants species.

Woodland Dynamics

Interactions and Succession

Many researchers comment on the reduction of understory vegetation as the western juniper canopy closes. However only two studies specifically addressed the plant to plant interactions over time and these two relied on age and size as a sequence in time. No long term before and after studies are available.

Adams (1975) aged and dated living and dead individuals of western juniper, bitterbrush, big sagebrush, gray rabbitbrush and green rabbitbrush by ring counts. This study was done at Ward Lake near the town of Silver Lake, Oregon, on a mule deer winter range. Of 228 western juniper specimens collected no dead were found. Establishment was clustered between 1900 and the mid 1930s. A high percentage of bitterbrush and big sagebrush plants were dead, 77% of bitterbrush (1,594/ha total plants, 645/ac) and 85% of big sagebrush (4,979/ha total plants, 2,015/ac).

Adams (1975) found densities of juniper increased up to 410/ha (166/ac) by 1971. Bitterbrush began a drastic decline in the late 1940s and sagebrush began a similar decline in the late 1950s to about 32% and 31%, respectively, of their populations in the early 1900s. He concluded that high juniper densities did not increase mortality of bitterbrush. Rather bitterbrush population declines were due to lack of regeneration. The normal age span (71 years) of bitterbrush did not change with increasing juniper dominance. However indications of reduced growth were present. A similar decline occurred with sagebrush as well, although the average age span was 20 years.

Populations gray and green rabbitbrush increased during in the late 1940s, green rabbitbrush more so than gray rabbitbrush. Interactions with grazing and precipitation but could not be determined absolutely due to unaccounted for historical events.

Tree size was used as an index to change in phytomass production over time in a study near Prineville, Oregon (Vaitkus and Eddleman 1991). Both the canopy zone and the interspace zone were sampled on two soils, one a shallow soil, 33 cm (13 in) deep at 1,140 m (3,740 ft) elevation and the other a moderately deep soil, 74 cm (29 in) deep, at 1,220 m (4,000 ft) elevation. Both soils were clayey and on a gentle slope with a north aspect, and both had a long history of heavy winter and early spring grazing by cattle, but were not grazed during the study.

Tree sizes sampled were small (1 to 3 m, 3.3 to 9.9 ft, canopy diameter and average 40 years old), intermediate (3 to 5 m, 9.9 to 16.4 ft, canopy diameter and averaged 55 years old) and large (5 to 9 m, 16.4 to 29.5 ft, canopy diameter and averaged 75 years old). Five randomly selected trees in each of the three size classes were sampled on the two areas in each of two years.

October through June precipitation during the sampling period was well above average, 420 and 480 mm (16,5 and 18.9 in) at the lower site and 454 and 494 mm (17.8 an 19.4

in) at the upper site for the first and second year respectively. This compares with a 30 year average of 235 mm (9.2 in) at Prineville which is at 886 m (2,906 ft) elevation and 8.8 km (5.5 mi.) away from the study site..

Both tree size and zone, canopy and interspace, influenced phytomass production. Sites with larger trees showed higher production of squirreltail, bluebunch wheatgrass, cheatgrass as well as some other annual grasses, and perennial and annual forbs. This might have had less to do with productivity capabilities than it did with the large trees acting as refuges from grazing. Sandberg bluegrass showed no production change to tree size. As tree size increased cheatgrass production increased in both the canopy and interspace zone. The canopy zone favored production of all of the above species and groups, but Sandberg bluegrass always produced more phytomass in the interspace zone.

The results of this study illustrate plant interactions in the presence of heavy grazing. Whether or not these areas would show the same interactions under proper grazing or with no grazing, is a matter of conjecture. The study by Evans and Young (1985) in northeastern California indicated almost no vegetation beneath the juniper canopies. This area had been heavily grazed with the intercanopy areas essentially being an annual grassland, the result of grazing, fire and competition.

As noted in other sections, a rather large gap in our knowledge exist for large physiographic land units within the western juniper type.

Although succession is not well understood in the young western juniper woodlands, great opportunities exist for establishing a solid base of successional knowledge. Many young woodland areas are currently undergoing successional changes. Additionally, the beginning stages of successional change are areas where high densities of seedling and juvenile western juniper trees are present on a broad range of plant associations and ecological sites. This latter situation offers the potential of establishing long-term baseline studies.

Fire Influences

Fire in the western juniper woodlands has been investigated by Bunting (1984), Burkhardt and Tisdale (1976), Johnson and Smathers (1976), Martin (1978), Martin and Johnson (1979), Quinsey (1984), Shinn (1980), and Young and Evans (1981). Reviews on fire effects (Volland and Dell 1981) and the role and use of fire in pinyon-juniper rangelands (Wright et al. 1979) provides useful information for planned burning in western juniper woodlands, the response to fire on a plant species basis is especially useful.

Broadcast burning in juniper woodlands used by native peoples was a common cultural practice which continued up to historic times (Martin and Johnson 1976, and Shinn 1980). With European settlement a period of promiscuous burning occurred in some areas (Shinn 1980). Griffiths (1902) makes negative comments on what he considers to be too much burning of mountain vegetation of southeast Oregon. Young and Evans (1981) found no evidence of promiscuous burning following settlement in northeast California. Rather, they found the latest fire scars on western juniper to have originated between 1850 and 1860.

Shortly after settlement a fire exclusion policy came into practice. It is likely that loss of fuels to carry fire played a much larger role in fire frequency reduction than did active suppression (Burkhardt and Tisdale 1969, 1976, Martin and Johnson 1979, Shinn 1980).

Lightning fires have been common in the western juniper woodland (Shinn 1980). Martin and Johnson (1976) note that 67% of the fires in the Lava Beds National Monument region of northcentral California were started by lightning. Pre-settlement fire periodicity on the Lava Beds National Monument was assumed to ranged from 5 to 15 years by Martin and Johnson (1976). Johnson and Smather (1976) note 75 lightning caused fires in a 41 year period on Lava Beds. Analysis of fires that occurred in the western juniper woodlands on Lava Beds yielded a fire frequency of 2.1 years. Martin and Johnson (1976) further conclude that, of lighting caused fires, 45% were in July, 14% were in August and 16% were in September.

Burkhardt and Tisdale (1976) concluded that some portion of the Owyhee Plateau burned every year. Fires burning through the old (climax) woodlands were spotty and of low intensity. Very little evidence of fire was found in the young woodlands perhaps due to a marked reduction of fires about 1910. Longer fire intervals are also found in the literature. Young and Evans (1981) working in northeastern Nevada, considered their data to indicate large scale fires were close to 100 years apart. They also note the presence of relatively fire-safe areas which were upper slopes protected by lack of fuels downslope, but they do not consider these areas as fire proof. Burkhardt and Tisdale (1976) found no evidence of fire in an 88 year old stand on the Owyhee Plateau.

Smaller western juniper trees, up to 4 meters tall, are readily killed by fire (Burkhardt and Tisdale 1976, Martin 1978, Martin and Johnson 1976, Quinsey 1984) while larger trees may be killed if heavily scorched or if the cambium is girdled by fire.

The above findings suggest that, in pre-settlement times fires generally left the landscape with a mosaic of scattered woodlands and that perhaps once per century broad-scale fires reduced many of these woodlands to widely scattered trees with woodlands surviving on some upper slopes and rocky breaks areas where lack of sufficient fine fuels prevented fire from reaching the stands or limited fire effects to scars on old trees (Burkhardt and Tisdale 1969, 1976; Caraher 1978).

Post-settlement fire exclusion appears to be a causal factor in the re-expansion of young woodlands across broad areas. Burkhardt and Tisdale (1976) considered fire control, reduction of understory fuel by grazing and a warmer drier climate that produced less fuel, as contributors to reduced fire frequencies in western juniper woodlands. Relatively high incidence of lightning caused fires occurring well into the grazing season (Martin and Johnson (1976), producing a steadily declining fuel base, lends support to the grazing reduction of understory fuels as a significant contributor to reduced fire frequencies.

Present bio-physical conditions in young western juniper woodlands are still in a period of transition due to a shift away from pre-settlement fire frequencies. Western juniper was not the only plant species influenced by fire, therefore the presence or absence, as well as general abundance of individual plant species as the result of fire exclusion, is critical to understanding community dynamics. At the same time, re-introduction of fire after a long exclusion period may result in assemblages of plants not associated with pre-settlement fire frequencies or with fire exclusion. Introduction of such species as cheatgrass and medusahead (*Taeniatherum asperum*), which can markedly increase after burning compared to most indigenous species, creates other new assemblages of plant species which will not come to a reasonable equilibrium for many years, whether burned or not.

The one study on plant response to burning in western juniper woodlands was made in central Oregon on the Crooked River National Grasslands (Quinsey 1984). This study is so confounded by unequal treatment of study plots both prior to and following fire, that cause-effect conclusions are suspect.

Western juniper on moist sites had a relatively high juniper cover eight years after a fire while on xeric sites its cover was still very low on a 20 year old burn. Big sagebrush reestablished well from burning on the moist sites although plants were small, but the response was variable on the xeric sites. Gray rabbitbrush tended to have higher population on burned sites than on unburned ones. No bitterbrush was found on the burned xeric sites but may have been recovering on burns of the moist sites.

Annual grass made up over 50% of the cover on the xeric 2-year-old burn of which only 4% was native annual grass and 96% was cheatgrass. Older xeric burns had about one-half as much annual grass cover while burns on moist sites had very low annual grass cover (< 5%).

Total perennial grass cover was not different on burned and unburned moist sites. The principle species involved were bluebunch wheatgrass, Idaho fescue, Sandberg bluegrass, squirreltail, and junegrass (*Koeleria cristata*).

Burned xeric sites showed higher cover of bluebunch wheatgrass than control plots. Xeric control sites were dominated by Sandberg bluegrass (8.1%) while xeric 6 year old burned areas had about the same Sandberg bluegrass cover but also had a significant cover of bluebunch wheatgrass (6.1%) and squirreltail (2.8%).

Total forb cover on burned mesic sites was not different from controls. Forb cover under all conditions was about 2 to 3% except for the 6-year-old xeric burn where forb cover was 9.7%.

● As noted above cause-effect relationships should not be used from this study; however, the data are useful for indicating intra-plot relationships.

Response of plant species to fire in pinyon-juniper are summarized by Wright et al. (1979) and Volland and Dell (1981). General responses to fire of individual plant species were given by Bunting (1984) and are presented below:

Mountain big sagebrush - rapid recovery by seed
Bitterbrush - low resprouting potential (6%), low seedling establishment rates;
Snowbrush ceanothus (*Ceanothus velutinus*) - increase
Idaho fescue - 25-40% mortality
Bluebunch wheatgrass - not greatly harmed, rapid recovery
Thurber's needlegrass (*Stipa thuberiana*) - sensitive

Martin (1978) and Martin and Johnson (1979) suggested that in the absence of fire and with or without grazing sagebrush-grass communities will go to juniper dominance but that when cheatgrass is present in the understory of juniper woodlands, fire and grazing will lead to communities with large amounts of cheatgrass. The tremendous increase in introduced annuals following western juniper control was also reported by Evans and Young (1985) and by Young et al. (1985). These annuals which may be present at low densities prior to tree control, but which can increase very rapidly, represent long term transitions in plant community structure and no data is available on the temporal transition length or the equilibrium community to be reached. Western juniper plant communities on xeric sites with inherent low plant cover appear to be the most susceptible to this transition.

Grazing Influences

Information on the effect of grazing by domestic livestock on western juniper woodlands is essentially anecdotal. Comments by various authors cited above give credence to the significant impact of uncontrolled grazing on woodland development up until the early 1900s. Specifically noted is the grazing reduction in fuels necessary to carry killing fire over broad landscapes and an increase in big sagebrush density which, as noted earlier, provides the bulk of the safe or favorable sites for juniper establishment. Where these conditions still exist in the mountain sagebrush type, whether due to present overgrazing practices or whether they exist as relicts from past events might make little difference, vulnerability to western juniper expansion appears to be enhanced.

Research data that would sort out the differential effects due 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. Additionally, differences should exist among old and young woodlands as well as even-aged and uneven-aged woodlands. Improper grazing has its impact on any plant community. However the threshold for radical vegetation or soil change may be much lower in areas occupied by large dominant woody evergreen plant species which are not eaten than in situations where they are not present. For this reason grazing studies from the sagebrush-steppe would only be generally applicable to western juniper woodlands.

Only one general study, Dealy et al. (1978a, 1978b) addresses a grazed vs ungrazed situation in a western juniper woodland. They examined a fenceline contrast in central Oregon where soils and aspect were similar. Average values were given for understory plant cover and cover and density for juniper. The ungrazed area had 10% juniper cover, 5% shrub cover, 46% grass cover, and 5% forb cover. The grazed area had 25% juniper cover, 6% shrub cover, 9% grass cover and 3% forb cover. All age classes of bitterbrush were found on the ungrazed area but only the mature age class was found on the grazed area. Nothing is known about the grazing history or fire history on either side of the fence except for the conditions present during the time of the study, grazed and ungrazed.

Juniper woodlands may be very responsive to grazing intensity. A study in blueberry juniper (*Juniperus ashei*) woodlands of Texas, reported by Smeins and co-workers (1994), showed no difference in herbaceous biomass production between heavy and light grazing. Pastures had been subjected to heavy continuous grazing and to moderately stocked deferred-rotation grazing, respectively. Herbaceous biomass production in ungrazed pastures was considerably higher at the canopy edge as well as in the intercanopy zone than in either of the grazed conditions.

Driscoll's study on the "Island" in central Oregon (Driscoll 1964a) which has been essentially ungrazed and which receives on the average about 235 mm (9.26 in) of annual precipitation and is therefore at the xeric end of the western juniper zone provides a partial basis for assessing grazing effects in surrounding areas. However, even on the "Island" cheatgrass forms a significant part of the system and may have been introduced by hikers, mule deer, or by sheep which grazed the "Island" for two summers during the 1920s.

The following cover values were given for the *Juniperus/Artemisia/ Agropyron* plant association on the "Island":

Juniperus occidentalis	10.0% cover
Artemisia tridentata	8.5
Chrysothamnus nauseosus	1.1
Total shrub	**9.6% cover**
Agropyron spicatum	9.2
Stipa thuberiana	2.0
Poa secunda	1.3
Festuca idahoensis	0.4
Sitanion hystrix	0.1
Total Perennial grass	**13.0% cover**

Festuca octoflora	0.6
Bromus tectorum	1.7
Total annual grass	**2.3% cover**
Lomatium triternatum	0.6
Other Per. Forbs	0.6
Total perennial forb	**1.2**
Annual forbs	0.1
Total herbaceous	**16.6% cover**
Basal area perennial herbs	6.6%
Bare soil surface	41.3%
Litter cover	30.7%

Driscoll reports a similar plant association and site near the "Island", but which was heavily grazed, had a perennial grass cover of less than 4% with cheatgrass cover being approximately 30%. Again, the grazed area can be classified as having been heavily grazed but no other information is available.

Data from the "Island" are only generally useful since herbaceous plant cover, bare ground and litter fluctuate considerably from year to year depending on effective precipitation.

Remnant vegetation on sites with long-term heavy grazing where kind of animal, season of use, etc. are not known is of little use in understanding grazing influences and developing grazing management strategies. Data from young woodlands are suspect in the sense that these stands are in transition and when fully mature may respond differently than when in developmental phase. Process changes involve many years dependent on the stand reaching maturity.

The effects of trees and grazing are generally inseparable in the literature.

Finally, no before and after studies have been completed.

Microbiotic Soil Crusts

Introduction

Microbiotic crusts are included in this assessment only because they represent an area of science unstudied in the western juniper woodland. No functional studies were available nor were process studies. The information contained here may more properly reside in other areas of the science assessment, however it has a bearing on how the western juniper woodland ecosystems function and should be acknowledged. The value of certain types of crust in protecting degraded sites from erosion is a subject of frequent speculation on in the literature, but there may be significant differences depending on crust species and other factors. Interactions in successional processes in juniper woodlands are likely significant but unstudied, as are interactions with grazing and fire. The information which follows may be most useful for realization that research on crusts is needed in the western juniper woodland to guard against unwarranted speculation.

Microbiotic crusts are common in the arid and semi-arid regions of the west and well developed crusts occur throughout the Great Basin Desert, the semideserts of the Colorado Plateau, and in sagebrush and pinyon-juniper communities of Utah, Nevada, Arizona, Colorado, New Mexico, and Wyoming. Microbiotic crusts are conspicuous on the gypsiferous soils of central and southern Utah, southern Nevada, and northern Arizona (Anderson et al. 1982). These microbiotic crusts also occur in western juniper woodlands of central Oregon (Quinsey 1984), and mountain big sagebrush communities.

Research focusing on soil crusts and surface cryptogams has been done in many areas with taxonomic and nitrogen fixation studies dominating the literature. Nitrogen fixation in particular is well documented (Henriksson and Simu 1971, MacGregor and Johnson 1971, Reddy and Gibbons 1974, Rychert and Skujins 1974, Shields et al. 1957, Snyder and Wullstein 1973) (referenced by Anderson et al. 1982).

More recent studies have focused on trying to quantify disturbance effects caused primarily by fire or excessive domestic livestock grazing, crust recovery rates, and assessment methods for crust biomass (Belnap 1993, Cole 1990, Johansen and St. Clair 1986, Johansen et al. 1982). Causal relationships between physical and chemical soil factors and crust development and vigor have been investigated by Anderson et al. (1982) and Kleiner and Harper (1977).

The intent of this literature search was to identify those research studies which focused on microbiotic soil crusts located specifically in western juniper woodlands, mountain big sagebrush communities, and the associated zone of pinyon-juniper woodlands.

In general, data pertaining to microbiotic crusts occurring in the northern Great Basin ecological region, the mountain big sagebrush habitat type, or in the western juniper woodlands is non-existent or extremely limited.

The pinyon-juniper systems of the Colorado Plateau and southwest have received more attention, but even there microbiotic crust data are limited. Data obtained from studies in those areas having summer or bimodal rainfall distribution patterns, may or may not be valid comparisons for effects occurring under the influence of the winter precipitation experienced by western juniper.

Information located in this search basically fell into six categories: disturbance effects, crust influence on subsoil properties, crust functionality, spatial distribution of components within the soil crust itself, survey type studies, and soil fauna. The results are discussed under these separate headings.

This search examined only a subset of the microbiotic crust research that has been done on rangelands around the world, particularly Australia, the Middle East, and Africa; however, reviews and extensive bibliographies are found in Dunne (1989), Harper and Marble (1988), Isichei (1990), Johansen (1993), Metting (1991), and West (1990) (St. Clair and Johansen 1993).

Effects of Disturbance on Microbiotic Crusts

Quinsey (1984) attempted to assess the effects of fire and grazing on vascular and non-vascular vegetation in the western juniper ecosystem of central Oregon. Cover, species composition, and density measurements were made on western juniper trees, shrubs, grasses, forbs, and mosses plus lichens, which were classed as cryptogams, growing in a set of plots that constituted a xeric chronosequence, a set of moist plots, and a pristine site in the Crooked River National Grassland in Jefferson County, south of Madras, Oregon. Climate is semiarid and continental with an annual precipitation of 240 mm, falling mostly as rain and snow in autumn, winter, and early spring.

The xeric complex was centered near Round Butte, and the moist complex centered around Pine Ridge (Quinsey 1984). The two complexes had very similar average cover (%) values for:

	Xeric	Moist
Juniper	7.0	7.4
Total forbs	2.2	2.9
Bare ground	35.5	34.4
Litter	40.3	42.9
Moss-Lichen	8.0	7.4

But there were strong differences in the average cover and species composition of shrubs and grasses between the two sites (Quinsey 1984).

The xeric sites had dense populations of relatively small-statured shrubs, which achieved only moderate cover; annual grasses dominated (13.6%) with cheatgrass co-dominant with Sandberg bluegrass (Quinsey 1984).

Individual plants of shrubs and grasses were much larger on the moist sites and achieved high cover even though they were fewer. The moist complex was dominated by perennial grasses (25%) mainly Idaho fescue, bluebunch wheatgrass, and Sandberg bluegrass. Annual grasses were <1% (Quinsey 1984).

Plots within the xeric complex were sufficiently similar to constitute a valid chronosequence, and were grouped together. The vegetation and soil differences on the moist site were questionable enough to invalidate that plot series as a chronosequence, and it was interpreted separately (Quinsey 1984).

Mosses and lichens were absent from the 2-year xeric burn, and made up <0.1% cover on the 6-year xeric burn compared to an 8% average for the xeric controls (Quincey 1984). However, on the 20-year xeric burn, moss-lichen cover was 15.9% which was not statistically different from that on the 20-year control (10.9%). In the moist complex, moss-lichen cover was 2.4% on the 2-year old burn and 11.4% on the control. The 8-year old burn had 6% moss-lichen cover versus 3.3% for the moist control (Quinsey 1984).

Moss-lichen cover was similar on the pristine site (10.9%) as compared to the average on the xeric controls (8.1%) (Quinsey 1984).

Although this study set out to quantify the effects of disturbance to this system and presents the results as increases or decreases of moss-lichen cover by treatment, these results are confounded by the research methodology employed and site differences both for initial vegetation and soil.

The research methodology depended on a set of sites which were similar enough to be considered a successional chronosequence using time since burn as the distinguishing factor. Even though this is a common technique, by using it, at best, only inferences can be made about the pre-burn and pre-grazing crust condition on the sites.

No information is available on season or intensity of either disturbance, fire or grazing, either pre- or post-burn. No actual pre-burn and pre-grazing measurements were made on the exact same plots, therefore, no direct comparison linking cause and effect can be made from the data. The study is only a survey of the vegetation and moss-lichen crust cover on the site at the time the study was done (1984).

As West (1990) points out in his discussion of soil erosion, no one has yet reported results of studies where comparisons have been made after initial inventories and removals or reductions were randomly assigned and erosion was subsequently compared to that on untreated controls. This seems to also be the case for many grazing impact studies. Few investigators have tried to sort out the degree of change affected by livestock versus other impacts and natural fluctuations.

Beymer and Klopatek (1991a) and Brotherson et al. (1983) were the only two studies encountered in this search which investigated the results of long-term grazing on microbiotics in old pinyon-juniper woodlands, both in northern Arizona. In the latter study cyanobacteria were not included.

Both studies found a significant reduction in total amount of cover of microbiotic crusts on grazed sites (compared to ungrazed), and Brotherson et al. (1983) also reported a reduction in non-vascular species diversity which is consistent with the findings of other investigators working in arid and semiarid shrub-dominated systems (Andersen et al. 1982).

Beymer and Klopatek (1991a), on the other hand, reported that species presence of microbiotic crusts showed no definite pattern relative to the amount of grazing. The impact of grazing resulted only in a reduction of total microbiotic crusts and biomass rather than a loss of species.

Both studies reported significantly less grass cover with significantly more bare soil on the grazed sites indicating that a decline in microbiotic crust cover results in more bare ground and not more vascular plant cover (Beymer and Klopatek 1991a).

Table 9. Relationship of grazed and ungrazed conditions to cover of crusts, grasses, and bare soil.

	% Microbiotic Cover		**% Cover Grass**		**% Bare Soil**	
	Grazed	**Ungrazed**	**Grazed**	**Ungrazed**	**Grazed**	**Ungrazed**
	(means)		**(means)**		**(means)**	
Beymer and Klopatek (1991a)	5.1	23.3	10.6	19.2	30.0	11.0
species	24	26				
Brotherson et al. (1983)	17.4	53.6	4.5	10.5	41.3	14.7
species	8	22				

Neither study reported correlations between cover of microbiotic crusts and soil property data, i.e. pH, % silt content, or electrical conductivity. Andersen et al. (1982) working in Utah found that soil texture and pH were influential in controlling the number of lichen and moss species per quadrat. Species diversity also appeared to increases as the surface content of soil, silt and clay, increases (Anderson et al. 1982).

Beymer and Klopatek (1991a) used five similar site locations on the Colorado Plateau and Kaibab National Forest, representing a continuum of grazing ranging from pristine (never grazed) to currently grazed during their study. All sites were at similar elevations and are underlain by Kaibab limestone covered with thin rocky soil (lithic entisols) whose properties did not vary significantly. Neither type nor density of domestic livestock using the sites was reported.

Brotherson et al. (1983) used transects across a fenceline at Navajo National Monument inside of which grazing has been excluded for the past 40 years. Grazing outside had occurred since the late 1890s with sheep and since the early 1960s with sheep and cattle. Grazing was year round with greatest utilization of the range being from early spring until late fall. Grazing pressure was moderate to heavy.

Percent cover of vascular and non-vascular species was estimated in quadrats using the ocular estimate method and cover classes proposed by Daubenmire (1959). Non-vascular cover was estimated and subdivided into 6 classes (lichens, mosses, algae, litter, soil, and rock) and recorded (Brotherson et al. 1983).

Beymer and Klopatek (1991a) collected 24 surface samples for crust biomass estimated using chlorophyll A content of the crusts. These samples were taken only in the interspaces. Their personal observations showed that crusts generally did not establish on litter under pinyon and juniper canopies. Samples were only taken from the intercanopy between tree canopies.

Microbiotic crust may recover faster than grasses from severe disturbance. In a pinyon-juniper watershed runoff study in north-central New Mexico, Wilcox (1994) measured microbiotic crust (in this study microbiotic crust and moss) on two 30 m^2 (323 ft^2) plots from which all vegetation, microbiotic crusts, litter, and rock had been removed four years prior. These plots were in the intercanopy between trees. At the time of measurement, four years after disturbance, microbiotic crusts and moss covered 26.6 and 29.1% of the surface on the two plots, slightly more than 50% of that on intercanopy areas which had not been grazed by domestic livestock for 50 years. Grass cover had risen to about 5% for both disturbed plots, a little less than 50% that of the ungrazed plots.

Cole (1990) studied controlled trampling of microbiotic crusts by hikers to determine how rapidly the crusts were pulverized and how rapidly they recovered. This is the only study encountered in this search in which all data was measured prior to and after trampling on the same plot. The vegetation type was a (blackbrush) *Coleogyne ramosissima-Pinus edulis-Juniperus osteosperma* woodland. Soils, derived from sandstones of the Supai Group are shallow and highly sandy.

Only 15 trampling passes were required to reduce the crust cover by 50% and to destroy the structure of the crusts; visual evidence of bacteria and cryptogam cover was reduced to near zero after 250 passes. Soil crusts redeveloped in just one to three years, and after 5 years the extensive bacteria and cryptogam cover left little visual evidence of disturbance. Surface irregularity remained low after 5 years, however, suggesting that recovery was incomplete (Cole 1990).

Changes in microbiotic crusts, vertical distance (flattened pedestals), and the index of surface roughness (variability of vertical distances across each transect provided an indication of surface roughness) were all statistically significant. Differences between the effects of trampling with tennis shoes and boots were not significant (Cole 1990).

Prior estimates of time for natural recovery of microbiotic crusts from disturbance have varied widely, ranging from a few years to 100 years for full recovery of all components (Belnap 1993). Therefore, estimates of these recovery rates seem quite rapid, but are supported by Belnap's (1993) inoculant use trials.

However, Belnap (1993) also notes that visual measurements cannot quantify the amount of cyanobacteria/green algae present, since filaments and cells ramify through several millimeters of surface soils. She recommends a type of chlorophyll A analysis and also a method to determine percent of nonliving filaments still present which bind soil aggregates together.

Crust Influence on Soil Properties and Seedling Establishment

Only two studies encountered that specifically looked at microbiotic crusts in pinyon-juniper woodlands with respect to influence on infiltration rates, permeability, potential sediment production, and chemical properties of the soil (Loope and Gifford 1972 (Utah) and Brotherson and Rushforth 1983 (Arizona)). Loope and Gifford (1972) working on the Colorado Plateau studied microbiotic crusts/soil properties along a site gradient from relict to chained with debris windrowed. Brotherson and Rushforth (1983) working in the Navajo National monument area of Arizona used five sites where crusts had been heavily disturbed or destroyed. Loope and Gifford (1972) evaluated the influence of a soil crust composed of crustose lichens, and Brotherson and Rushforth (1983) examined moss, lichen, and algae cover. This component variation between the two studies is easy to overlook, but may be important to interpreting and comparing their results.

Loope and Gifford (1972) reported that high lichen cover significantly impeded permeability, and in general, the greater the lichen cover, the greater the resistance to permeability (Table 10). But that a high lichen cover significantly increases infiltration rates.

Table 10. Permeability, infiltration and sediment production associated with microbiotic crusts on the Colorado Plateau.

	Intrinsic Permeability ($\mathbf{cm^2 \times 10^{-8}}$)	**Infiltration Rate** **(cm/hr)**	**Sediment Production** **(kg/ha)***
A relict	.64	7.08	269
B near relict	.44	6.85	784
C intermediate	.50	7.13	538
D livestock paths/waterways	.98	6.93	1,053
E chained/debris in place	.63	5.15	605

F chained/debris windrowed	.80	5.68	560

* x 0.893 = lbs/ac

(from Loope and Gifford 1972)

Brotherson and Rushforth (1983) in a field study found that a well developed microbiotic crust significantly increased the depth of water penetration and supported this by saying that this result was also found by Loope and Gifford (1972). The data indicate just the opposite. Hence comments by West (1990).

Brotherson and Rushforth (1983) also found that where moss cover was high, infiltration rates were greatly enhanced over areas where moss had been removed. They report that infiltration was significantly reduced or impeded by lichen and algal crust cover and again support their data with Loope and Gifford (1972). But Loope and Gifford (1972) only looked at crustose lichen cover, so again the studies showed differing results by comparing "apples or oranges."

Both studies do agree that some microbiotic crusts do help infiltration by increasing microsurface topography by forming pedestals and microdepressions where water can pond and sink into the surface slowly. Although there was no significant difference between bare soil and crust covered soil in sediment production, Loope and Gifford (1972) report a trend toward bare soil being more subject to soil movement and erosion.

Loope and Gifford (1972) found that soil properties were not strongly influenced by the amount of microbiotic crust cover, and that organic matter and pH produced no significant differences among crust conditions or soil depths.

Two main differences in study methods were: (1) Loope and Gifford (1972) worked with core samples taken from the field, while Brotherson and Rushforth (1983) worked strictly in the field, and (2) the treatments applied to Loope and Gifford's (1972) sites consisted of mechanical deformations where Brotherson and Rushforth (1983) did not report the method of disturbance.

This result differs from Anderson et al. (1982) also working in Utah, who reported that the vigor of development of the microbiotic crusts is closely correlated to soil chemistry and texture. Soil texture and pH were the apparently influential variables controlling the number of lichen and moss species per quadrant. Soil texture was also strongly correlated to the number of algae species per transect. Soil electrical conductivity, pH, and soil phosphorus accounted for 3/4 of the variation in microbiotic crusts (Anderson et al. 182).

Greenhouse studies were conducted by Schlatterer and Tisdale (1969) to study the role of brush litter and microbiotic crust cover on grass seedling emergence and establishment. No studies were found specifically relating to impacts on juniper seedlings in woodland settings, but this study is included here because *Tortula* moss is of interest and abundant in old western juniper woodlands.

Litter of microbiotic moss, big sagebrush, and green rabbitbrush retarded germination and early growth of Thurber's needlegrass, squirreltail, and bluebunch wheatgrass. Four weeks after germination, growth was stimulated by the presence of the same litter materials. Stimulation was attributed to a greater availability of nitrogen in the *Tortula* moss and sagebrush litter, but in the case of rabbitbrush there was some evidence for the occurrence of an additional growth-promoting substance (Schlatterer and Tisdale 1969).

There are studies that show high inverse correlations between seedling abundance of both tall and chenopod shrubs to microbiotic crusts, but more show a positive correlation between the cover of vascular plants and the cover of microbiotic crusts. Crisp (1975) has shown how increased amounts of microbiotic crusts resulted in sorting out of higher plant species and attributes the increase to seed structures, i.e. Russian thistle (*Salsola*) with small, roundish seeds are prevented from breaking through the crusts. Needlegrass, however, has a hydroscopic awn and setae on the seed which can penetrate the crust (West 1990).

Evans and Ehleringer (1993) examined the soil nitrogen content and isotopic composition ($^{15}N/^{14}N$) within soils of a juniper woodland (Utah juniper interspersed with big sagebrush). Using the nitrogen content and isotopic composition ration of ($^{15}N/^{14}N$), and the Raleigh distillation kinetics model, they attempted to determine the original source of nitrogen input to the system.

From their range of results, they ruled out atmospheric deposition, anthropogenic nitrogen inputs, dry deposition and precipitation as potential sources for the increases in nitrogen that they found. Their results were consistent with delta ^{15}N values of nitrogen reported for other nitrogen-fixing organisms. Since other symbiotic or heterotrophic nitrogen fixers are not common in the arid regions, they concluded that the crypobiotic crusts were the original source of nitrogen to the woodlands.

Soils samples were taken from the intercanopy (designated disturbed soils) and from under the canopies of the juniper trees and sagebrush (intracanopy/undisturbed). Disturbance of the crust had resulted in considerable spatial variability in soil nitrogen content. Soil N content was greatest under the juniper canopies, and did not differ significantly between soils under sagebrush canopies and the intercanopy spaces (Evans and Ehleringer 1993). Most visible crust in their systems remained as remnant under the juniper and sagebrush vegetation, an opposite finding to that of Beymer and Klopatek (1991a) in pinyon-juniper.

Beymer and Klopatek (1991b) examined a pinyon-juniper woodland pinyon pine (*Pinus edulis* Engelm.) and Utah juniper to determine if microbiotic crusts contribute organic carbon directly to the ecosystem. They report that in general a downward translocation of photosynthate over time from the crust was demonstrated by an increase in C^{14} content in the soils beneath the crusts. Combined laboratory calculations of photosynthetic activity and field data, it appears that microbiotic crusts may contribute from 43 (grazed) to 350 (ungrazed) kg C/ha/yr in these woodlands, and as much as 2.5 kg may be leached directly into the soil (Klopatek 1991 referenced by Beymer and Klopatek 1991b).

The labile content excreted by the crust organisms is potentially a major source of nutrition to the large mass of heterotrophic soil micro-organisms (including nitrogen fixers) (Paul and Clark 989 referenced by Beymer and Klopatek 1991b). Since many of the eukaryotic algal members of the crust community may themselves be facultative heterotrophs, this carbon could also play a role in self-maintenance of the crust under adverse conditions (Beymer and Klopatek 1991b).

Spatial Heterogeneity Within Microbiotic Crusts

Algal density of microbiotic crusts under Utah juniper canopies was reported to vary by more than an order of magnitude with the samples examined. Algal patchiness could be as significant on a scale less than 0.013 m as it is on a scale of 24 m. Goodall's random pairing analysis of spatial pattern supported these conclusions by indicating that the minimal area for sampling soil algal crust populations (at that particular site) should be equal to or less than 0.013 m (Grondin and Johansen 1993).

Bacterial densities of microbiotic crusts under Utah juniper canopies was reported to show a range differing by several order of magnitude. Adjacent soil samples showed no more similarity to each other on the basis of bacterial density or taxa composition than did more widely separated samples (Wheeler et al. 1993).

Ladyman et al. (1993) estimated the influence of tree spacing on microbiotic crust abundance and compared two pinyon-juniper communities for the presence and abundance of terrestrial cryptogams along with their association with grasses and forbs. They had two sites one in Comanche Canyon and one at Largo Mesa in New Mexico pinyon-juniper communities.

The two sites were significantly different for the species present, and for the percent transect cover of both vascular plants and cryptogams (Ladyman et al. 1993). At both sites there was a negative association between percent line cover by the canopy and total microbiotic crust. At Comanche Canyon tree spacing greater than 4 m (13 ft) permitted a substantial crust cover. Woody debris and needle debris were both negatively associated with certain components of the microbiotic crust. At both sites, pebbles were positively associated with cryptogam colonization of adjacent soil (Ladyman et al. 1993).

Short distances (<4 m) between trees was correlated to a lack of development of crusts rich in lichens. In some instances areas with abundant grass cover have low cover of certain cryptogams. High forb cover was positively associated with some components of the microbiotic crust. The extent to which debris covered a line was inversely correlated with the amount of microbiotic crust on the line, but pebbles were positively correlated to high lichen cover.

The soil fungal community beneath pinyon pine and one-seeded juniper (*Juniperus monosperma* [Engelm] Sarg.) tree canopies was described and compared with fungi from adjacent interspace soils dominated by blue grama (*Bouteloua gracilis*) (Fresquez 1990). Significantly higher organic matter contents and fungal propagule levels were found in soils beneath pinyon and juniper trees than in interspace soils. Soils under pinyon and juniper trees contained similar chemical, physical, and microbiotic properties, and consequently many groups of fungi in common (65% of the species isolated were common to both). In contrast, soil fungi in adjacent interspace soils were vastly different from those collected in soils beneath pinyon and juniper canopies (44% and 48% species in common respectively) (Fresquez 1990).

Interspace soils contained the lowest number of fungal species isolated. Usually, soils that contain more organic matter have higher fungal populations but a lower fungal diversity than soils lower in organic matter (Dennis and Fresquez 1989, Fresquez 1990). Soils collected from under both pinyon and juniper canopies contained significantly higher fungal populations than interspace soils. Only the soil collected underneath pinyon trees had a lower fungal diversity index than the soil from the interspace soils.

Hydrologic Cycle

All hydrologic processes are of interest in the western juniper woodland ecosystem since they play dominant roles in sustaining site stability and productivity. Interception of precipitation, infiltration of water, runoff and erosion are processes of particular interest. Any process which removes, modifies or redistributes plant species, functional groups or plant communities will alter hydrologic processes in numerous ways. Water, sediments, and nutrients are redistributed by these processes. Grazing, burning and wood harvesting individually and collectively modify these processes.

Interception

Technically, all precipitation arriving at the earth's surface is intercepted by some physical structure whether it be water, bare soil, gravel, rock, cryptogams, litter, foliage, bark, stems, branches or boles. However, as used in the literature, interception is the processes of collection and redistribution of precipitation to the ground or back to the atmosphere by both living and dead vegetation. Dead vegetation includes both standing dead and litter on the soil surface.

The interception process usually is broken into canopy interception, litter interception, throughfall, and stem flow. **Interception** is that precipitation not accounted for by measurements of stem flow and throughfall. Canopy and litter interception are generally considered losses to the site via evaporation, however microbiotic activity, including fungi and invertebrates, is undoubtedly influenced on canopy surfaces and within litter by intercepted moisture. Additionally, changes in atmospheric temperature and humidity at the microenvironmental level will influence physiological processes of plants.

The process of interception has been investigated in several forest types. Interception by western juniper trees (n=10) was first investigated seasonally over a 4 year period by Young et al. (1984, reported again by Young and Evans 1987). They found **stem flow**, which is precipitation collected by the canopy that flows down the stem to the ground, averaged 0.53 L (1 L = 0.268 gal) per mm of precipitation. This represented a very small percentage of the precipitation but since it was concentrated around the bole base it was considered significant. Significance of stem flow was increased by the enrichment of nitrate-nitrogen and bases particularly associated with fall storms.

Average total stem flow ranged from 1.1 to 4.8 L in summer, 0.2 to 3.1 L in fall, 1.3 to 13.8 L in winter, and 2.8 to 15.2 L in spring. Only when stem flow was high, 8 L per tree, did it relate well to canopy diameter and tree height.

Throughfall, which is the amount of precipitation that penetrates the canopy or drips from the foliage and branches, was found to be on an annual basis 31%, 49% and 81% respectively at the trunk, halfway between the bole and canopy edge, and canopy edge with no difference existing between seasons. In one calculation the authors showed canopy interception to be 42% of the precipitation received by the canopy with a 235 mm (9.25 in) precipitation input. Storm intensities and duration were not accounted for in this study.

Another study on the interception process in western juniper trees and woodlands is that of Larsen (1993) in central Oregon. Larsen used simulated rainfall treatments on individual trees and determined the water holding capacity for small trees (n=32) and large trees (n=19). Woodland interception relative to canopy cover and litter interception were also measured. Small juniper trees (crown volumes ranging from 0.1 to 6.8 m^3) held 0.3 to 1.6 mm of precipitation while large trees (7 to 356 m^3 , 237-12,560 ft^3 , crown volume) held 0.9 to 4.7 mm of precipitation. Although the amounts expressed on an input basis seem small, the 4.7 mm represented 398 L (398 gal) of water. Water holding capacity was dependent on tree size with leaf biomass, bole biomass, total biomass, leaf area, basal diameter and branch biomass being significant variables.

When Larsen's simulated rainfall reached approximately 7 mm, stem flow was initiated on the large trees. Percent interception of each successive mm of water applied declined until saturation of the tree occurred at approximately 10 mm. When input reached 26 mm, stem flow ranged from 0.11 mm to 1.42 mm.

Canopy interception in natural woodlands (n=20) was dependent on gross precipitation of the storm event and canopy cover. Calculated interception ranged from 7.8% to 12.8% for canopy coverages of 9% to 43%. Interception declined with increasing canopy cover, apparently due to a decline in foliage density with increasing tree density and cover.

Interception of precipitation by litter is potentially very high. Average litter depths for large trees were 64, 27 and 10 mm respectively for the inner 1/3 of canopy radius, middle 1/3 of canopy radius and outer 1/3 of canopy radius. Water holding capacity measurements showed a 1 to 3 relationship, that is 1 mm of water penetrated 3 mm of litter or about 21, 9, and 3.3 mm of water respectively for the above 3 zones.

These two studies indicate the significant effect western juniper trees have on the hydrologic cycle due to the reduced amount of precipitation arriving at the soil surface. This effect is best examined at the storm event level, since storm size determines stem flow and throughfall. Smaller storms are likely to produce no stem flow and low throughfall which may be held in the litter. Net interception with subsequent evaporation or sublimation back into the atmosphere will be a high percentage of input for small storm events.

Measured interception of snowfall by vegetation is largely absent from the literature. Larsen's data contains only a few snowfall events. Most events were rain. Young and his co-workers (cited above) found an increase in interception during the winter when precipitation was largely snow.

Species and functional groups of plants that are associated with the western juniper woodlands show variable interception amounts, largely dependent on plant size, density, and aboveground biomass and amount of precipitation.

Hull (1972) found big sagebrush in a stand of 2.2 plants per m^2 to intercept 69% of rainfall (183 mm) and 61% of snow (38 mm). Ndawula-Senyimba et al. (1971) found moisture penetration was greater beneath bluebunch wheatgrass than in bare areas and that penetration increased with plant height. They attributed this phenomenon to foliar interception of precipitation which was then directed to the base of the plant.

Corbett and Crouse (1968) found yearly variation in interception by annual grasses of 5% to 14%, the higher interception percentages occurring in a year when above-ground biomass was very high during precipitation events. In a high producing mixed prairie vegetation (500 g/m^2 dead material and 140 g/m^2 live plants) Couturier and Riply (1973) found growing season interception in two years to be 14% and 22%. In grass stands interception actually lost may be minimal if the vegetation is green, perhaps due to reduced transpiration, however losses are significant when foliage is dry (McMillan and Burgy 1960).

Infiltration

Infiltration rates impact the amount of water stored in the soil profile. Water stored in soil on-site sustains, both on a temporal and spatial basis, the near surface and subsurface microbiotic processes which in turn determine the productivity of the site. Stored water also affects soil temperature which in turn controls both physical and microbiotic process rates. Conversely, water which does not infiltrate runs off the site to other ecosystems or evaporates back into the atmosphere.

Research on infiltration in western juniper woodlands is confined to two publications (Gaither 1981, and Gaither and Buckhouse 1982). The mean infiltration rate (66 mm/hr) for the juniper ecosystem was not different from sagebrush or grassland ecosystems. Within the juniper ecosystem the lowest productivity class had the lowest infiltration rate (41 mm/hr) but that of poor condition range was not different from that of fair condition in which condition class was based on vegetation composition.

In the research cited above considerable variation was found in infiltration rates which limit the usefulness of the results. However all studies on infiltration in arid and semiarid ecosystems will show a high degree of variation. Important contributors to that variation are numerous. Wood et al. (1987) developed a relationship model (Figure 1) which provides insight into the reason for the variation found in infiltration studies.

Wood et al. (1987) found those factors that best explained infiltration were grass production, litter production, total ground cover and soil sand fraction at 0-5 cm (all positively related), and soil moisture at 5-10 cm, bulk density, and silt fraction at 0-5 cm (all negatively related). On one watershed which had pinyon-juniper plus a wide

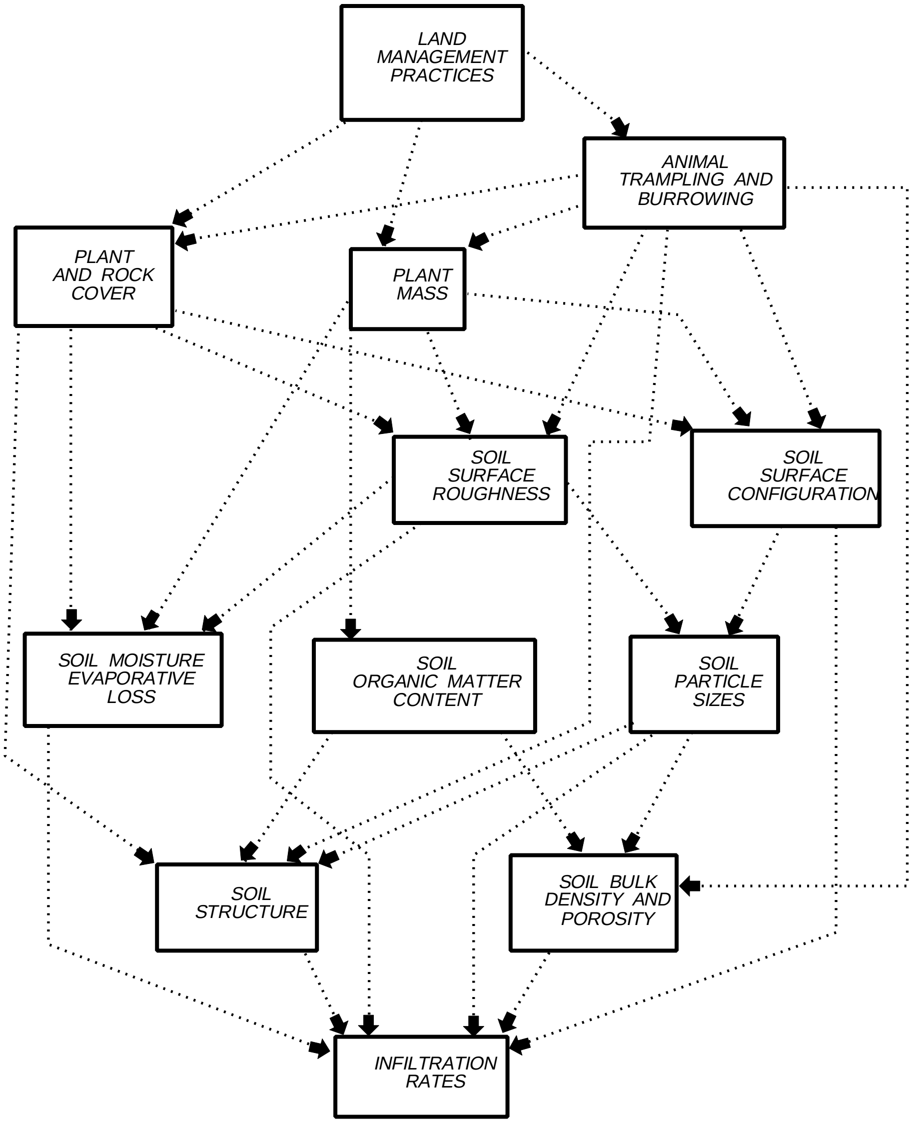

Figure 1. Relationships of plant and soil characteristics to infiltration rates (from Wood et al. 1987)

variety of treatments and little grazing control, variation within and between sites was high, reducing the coefficients of determination. One significant coefficient for this watershed was the negative effect of soil moisture in the surface 0-5 cm of soil which did not appear in the other watersheds.

Total porosity in the 0-7.5 cm of soil, percent bare soil, soil texture at 0-7.5 cm, vegetation canopy cover and kg/ha of aboveground biomass were related to infiltration rates on some Utah pinyon-juniper sites which had been chained (Williams et al. 1972). Wilcox et al. (1988) concluded that vegetational cover and aboveground biomass most strongly influenced infiltration on mountain slopes which included one-seed juniper as a common species. They summarized the positive influence on infiltration by vegetation as decreasing velocity of flow, increasing surface roughness, increasing infiltrability by root activity and organic matter additions, reduce raindrop energy, and reduced formation of impermeable crusts. They found grass production to be particularly important in these mixed communities; that for shallow soils small changes in soil depth had large impacts in infiltration; that rock cover was better than bare ground; and that infiltration was positively related to slope gradient. The reason for the latter remains speculative.

A significant finding in this study was that first- and second-year results were not always in agreement. This suggests that year-to-year variation needs to be accounted.

Additionally, factors which shorten slope length and increase detention storage (such as miniature terraces and plant dispersion), as well as microbiotic and vesicular crusts and current moisture status of the soil cause infiltration rates to vary (Blackburn 1973, Blackburn and Skau 1974, and Wood 1988). Considering the latter factor, infiltration rates decline with time, reaching a terminal rate (Wood 1988). Blackburn and Shau (1974) presented values for infiltration rates for 29 plant communities on four watersheds. In every instance the value given for the infiltration rate of soils at field capacity was less than that of dry soils. For example, in one watershed the dry and field capacity infiltration rates were 72 and 60 mm/hr (2.83 and 2.36 in/hr) respectively for a big sagebrush/bitterbrush/ bluebunch wheatgrass community and 65 and 45 mm/hr (2.56 and 1.77 in/hr) respectively for a singleleaf pinyon/Utah juniper community.

Vesicular soil horizons negatively affect infiltration (Blackburn 1973, Blackburn and Skau 1974) while microbiotic crusts appear to have a positive, neutral, or negative effect on infiltration rates depending on cover, density, surface roughness, hydrophobicity, color (influences evaporative potential) and other factors (West 1990, Harper and Marble 1988).

Juniper woodlands have a significant percentage of their area beneath the crowns of tree, which are litter accumulation zones. As previously noted, litter has a high water holding capacity. However both Larsen (1993) and Scholl (1971) found juniper litter to be highly unwettable when dry. Larsen, in making observations on litter wetting during simulated rainfall tests, found that moisture moved readily down through cracks which develop in dry litter.

Data from Blackburn (1973) and Blackburn and Skau (1974) suggest the need for determination of terminal infiltration rates in western juniper woodlands or associated types, over a broad range of conditions where controlling variables are identified. Such values will be necessary to predict sediment production as a function of site change.

Runoff, Erosion, and Sedimentation

The antithesis of infiltration is surface runoff. Not all runoff carries sediment, and not all sediment carried from an upper site to a lower site is bad. Concerns for erosion and sedimentation typically revolve around a possible loss in productivity for one or both sites, usually without regard to its temporal nature.

Sediment production is related strongly to those factors which influence infiltration plus others that relate to erodibility of the soil surface. Therefore sediment production tends to be negatively related to plant cover and aboveground biomass factors and positively related to bulk density, slope, and vesicular crusts (Blackburn 1973, Blackburn and Skau 1974, Wood et al. 1987, Wood 1988).

Sediment production from western juniper woodlands has been assessed at the ecological land unit and ecosystem level and at the habitat type (h.t.) level (Buckhouse and Mattison 1980, Gaither 1981, Mattison 1978). In the Bear Creek watershed in central Oregon mean sediment yields from a theoretical 25 year storm were 1,636 kg/ha (kg/ha x 0.893 = lbs/ac) for the juniper woodland (Buckhouse and Mattison 1980). Within this woodland mean sediment yields by habitat type were; 2,912 kg/ha for the western juniper/big sagebrush/Idaho fescue-bluebunch wheatgrass h.t., 411 kg/ha for the western juniper/big sagebrush/Idaho fescue-bluebunch wheatgrass h.t. Thurber's needlegrass phase, and 1,538 kg/ha for the western juniper/Thurber's needlegrass h.t.. One other habitat type with invading juniper, big sagebrush/Idaho fescue-bluebunch wheatgrass h.t. produced a mean sediment yield of 1,961 kg/ha. Variation in sediment yield rendered means not significantly different.

Sediment research in the upper John Day River watershed (Gaither 1981) for 25-year simulated rainstorms resulted in a mean yield of 1,572 kg/ha for western juniper woodland which was not different from the mean of 1,284 kg/ha for the sagebrush type. However, sediment yield from grassland was at 431 kg/ha.

A few related studies where site factors which influence variation in sediment yield were measured are available for comparison. Blackburn and Skau (1974) considered sediment production to be positively related to vesicular crusts and moisture content of the soil surface. In 23 out of 29 plant communities studied in Nevada sediment production values with surface soils at field capacity were higher than for those of dry soils. Dry and field capacity sediment productions were 179 and 807 kg/ha respectively for the big sagebrush/bitterbrush/bluebunch wheatgrass community and 448 and 1,165 kg/ha respectively for the singleleaf pinyon/Utah juniper community.

Gifford (1973) in a Utah pinyon-juniper study, reported higher sediment yield from areas chained with windrow treatments than for intact woodlands but that chaining with debris in place was similar to intact woodlands. Increased runoff and sediment yield from the chain with windrow treatment was attributed to destruction of microbiotic soil crusts and whole area contribution to runoff as opposed to only interspace contribution in the intact woodland.

Williams et al. (1972) examined numerous vegetational and soil factors in relation to erosion on Utah pinyon-juniper sites. Factors which influenced sediment yield proved to be too variable for relationships to be established.

Wilcox (1994) summarized runoff studies in the pinyon-juniper system (Table 11). Runoff was generally less than 10% except for three Beaver Creek (Arizona) watersheds. It is important to note that all small plot studies measure overland flow and not subsurface flow and as Wilcox (1994) noted runoff from small plots on a watershed may not result in runoff from the whole watershed.

Wilcox (1994) measured runoff from six 30 m^2 interspace pinyon-juniper plots over a two year period. Shrub cover (4.1 and 6.5%) and bare ground (46.8 and 61.1%) were high on severely disturbed plots (n=2). All vegetation, microbiotic crusts, litter and rock had been physically removed from these two plots four years previously. Cover of grass (8.1 to 22.7%), microbiotic crust (43.7 to 53.9%), and litter (16.3 to 20.5%) were high on the plots with negligible disturbance (n=4). These four plots had not been grazed for 50 years.

Most runoff occurred in mid summer and late winter and accounted for 10% to 28% of the water budget over the two years. Runoff made up 16% and 3% of the summer water budget, generated mainly by thunderstorms, and 44% and 29% of the winter water budget, generated by snowmelt. If only normal precipitation inputs are considered sediment yields on disturbed plots were 255 kg/ha or less in summer and on undisturbed plots were 79 kg/ha or less in the winter. During a wet summer sediment yields were thousands of kg/ha on disturbed plots and hundreds of kg/ha for undisturbed plots.

Wood (1988) states that "The greatest influence of plants on runoff is probably the changes in sinuosity of flow". He states that runoff pattern is determined by plant density, cover, phytomass, and distribution of plants across the site. Concentration of plant cover into larger units, i.e. 30% cover at low plant density rather than at high plant density, leads to concentration of flow, longer pathways and increased runoff and erosion.

Wilcox (1984) suggests that the following three hypotheses, proposed for other semiarid landscapes, were applicable to pinyon-juniper woodlands.

Table 11. Watershed and hillslope-scale hydrologic studies in pinyon-juniper environments.

Location	Number of sites	Size	Years active	Study purpose	Precipitation	Runoff		Dominant runoff season/event	References
					(mm)	(mm[a])	(%)		
Watershed studies									
Beaver Creek (AZ) (Watersheds 1, 2, 3)	3	51-146	22	Evaluate effect of P-J control (cabling, hand-slashing, burning, herbicide)	458	27	6	Winter (85%) (rain-on-snow, prolonged rain, snowmelt)	Clary et al. 1974; Baker 1982
Beaver Creek (AZ) (watersheds 4, 5, 6)	3	24-140	22	Evaluate effect of P-J control (cabling, hand-slashing, burning, herbicide)	526	121	23	Winter (97%) (rain-on-snow, prolonged rain, snowmelt)	Clary et al. 1974; Baker 1982
Carrizzo Creek (AZ)	1	62,382	12	Evaluate effect of P-J control (chaining, hand-slashing, burning)	457	18	4	Winter (90%)	Collings and Myrick 1966
Corduroy Creek (AZ)	1	55,166	12	Evaluate effect of P-J control (chaining, hand-slashing, burning)	457	24	5	Winter (93%)	Collings and Myrick 1966
Mexican Springs (NM)	9	1391-3437	6-20 2-6	SCS[b] characterization of P-J environment	283	13	5	Summer	Dortignac 1960
Santa Fe (NM)	3	31-319	10	SCS[b] characterization of P-J environment	327	7	2	Summer	Dortignac 1960
Hillslope studies									
Beaverhead (NM)	20	0.04	2	Evaluate impact of fuelwood cutting and burning	325	28	8	Runoff data collected only during the summer	Wood 1991
Baird (TX)	6	0	2	Evaluate impact of burning of juniper	613	23	4	Summer and Winter	Wright et al. 1976
Milford and Blanding (UT)		0.04	3	Evaluate effect of P-J control (chaining, win-rowing; chained debris left in place)	246	3	1	Summer (high-intensity thunderstorms)	Gifford 1975a

(from Wilcox 1994)

---

[a] = Data are for untreated (control) areas except where no control dasta were available.

[b] = SCS = Soil Conservation Service.

1. Runoff amounts vary with scale: runoff decreases as size of contributing area increases, more opportunity is provided for infiltration.

2. Infiltration capacity of soils is dynamic: it is closely tied to soil moisture content and/or soil frost conditions, both being major determinants of runoff amounts.

3. Soil erodibility follows an annual cycle: it is highest at the end of the freeze-thaw period of late winter and lowest at the end of the summer rainy period.

No research has been carried out specifically evaluating effects of plant density on infiltration and erosion. Many semi-arid and arid ecosystems are moving toward the coalescence of cover. Since expansion of western juniper into sagebrush-grass types is potentially a process of reducing plant densities and a coalescing of cover, research into these relationships would be useful.

Other significant deficiencies exist in addition to the lack of research on the effects of density or dispersion of vegetation on hydrologic processes. Difficulties in applying infiltration and sedimentation research results to western juniper woodlands arise from at least three sources:

1. Factors contributing to the variation in infiltration and sediment yield are noticeably absent from the literature for western juniper as well as related studies in the pinyon-juniper type, however, see Wood et al. 1987, Wilcox et al. 1988, Wilcox 1994. In most cases detailed descriptions and measurements of vegetation and soils are absent. Factor analysis may well require the use of small plots and simulated rainfall.

2. Use of small plots, usually less than 1 m^2 or less in size, negate the possibility of interpreting and applying the results of infiltration and sedimentation studies at the site or landscape level, however see Gifford (1973) and Wilcox (1994) who used large (30 m^2) runoff plots. Interaction of biophysical factors influencing these two processes is scale dependent and therefore considerable factor compensation as well as both positive and negative synergism is to be expected. The size of study plot would need to be sufficiently large to allow prevalent site factors to interact.

3. All the studies on infiltration and erosion cited as well as others which were reviewed, point to a major seasonal gap in research and therefore to our understanding of woodland hydrology. This gap is temporal extending from November through May, which is a biophysically dynamic period of major moisture input for the western juniper woodland.

There are many reasons for considering the winter/spring period as critical in the hydrologic cycle. Western juniper woodlands lie largely in a transition thermal belt. Reference has been made to the woodland as being thermal cover for wildlife in which snow cover typically lasts only a few days. Compared to like areas without juniper cover, these areas have low winds and high winter temperatures. Such environmental conditions potentially impact sublimation of snow, evaporation of moisture from the soil surface including that from needle ice activity, evaporation of moisture intercepted by plant canopies, and water use by evergreen plants. Infiltration and erosion are influenced by soil temperatures, frozen soil surfaces, needle ice activity and saturation of the surface horizons or in the case of shallow soils, saturation of the profile.

The work of Gifford and Shaw (1973) indicate the need for winter/spring hydrologic studies in woodlands. They examined soil moisture patterns on two areas in southern Utah's pinyon-juniper woodlands. Estimates of total soil moisture were made as early as late February and as late as mid December over a three year period. Woodland control plots had less soil moisture the first six months as compared to chained with debris-in-place treatment areas at one site and less moisture at all measurement dates at the other study site. The attributes differed in terms of moisture patterns due to differences in microclimate, rooting depth, length of growing season, mulching by debris, and possibly changes in snow accumulation.

Wildlife in Western Juniper Woodlands

Although western juniper is a major vegetation type in Oregon, good documentation and research relating to wildlife use of these woodlands or the impacts of management practices are very limited. This is particularly true for non-game species. Maser and Gashwiler (1977) concluded that little work had been done on the interrelationships of wildlife and western juniper. Following an extensive search through the literature this statement is still true 17 years later. Development of management guidelines has been derived from observation and information in other vegetation types due to a lack of information.

Of the estimated 341 animal species found in southeastern Oregon (Maser et al. 1984) 95 have been reported to occur in juniper steppe (Puchy and Marshall 1993). Juniper steppe is defined as western juniper woodlands, typically having sagebrush as an understory between the trees. Maser et al. (1984) attempted to describe the value of 16 different plant communities, based on structure, for the 341 vertebrate species occurring in southeastern Oregon. Of the 16 communities, western juniper/sagebrush/ bunchgrass had the third largest number of the 341 species. The community type used by the greatest number of species were riparian communities followed by tall sagebrush/bunchgrass. More recently Puchy and Marshall (1993) reported the occurrence of wildlife in juniper steppe (Table 12). Others have attempted to list species observed using the juniper woodlands (Elmore 1984). Although these provide good estimates, the following questions are raised:

1. What is the level of importance (e.g., casual use or critical habitat) of juniper woodlands?

2. Is it the tree canopy that is important, the understory or both? For example, the second most widely used community type second only to riparian, the big sagebrush bunchgrass type, has many species which also are observed in juniper steppe .

3. How does structure of the woodland; e.g., tree density and composition of the understory, influence wildlife use?

4. Since many of these woodlands are in a dynamic state, what is desirable now may be lost as the overstory closes in; e.g., as tree canopy increases the understory usually decreases, especially the shrub component, and diversity of the plant community diminishes.

Large Herbivores

Probably the most extensive information on wildlife use of western juniper community types was done in the Silver Lake region of eastern Oregon during the 1960s and 1970s. Leckenby and others (1971) studied various aspects of mule deer winter range across several plant communities in central Oregon. In this area, fawn survival rate

Table 12. List of wildlife species observed in western juniper communities.

SPECIES	JUNIPER STEPPE
AMPHIBIANS	
Long-toed Salamander *Ambystoma macrodactylum*	X
Pacific Treefrog *Pseudacris regilla*	X, F
REPTILES	
Western Fence Lizard *Sceloporus occidentalis*	X
Sagebrush Lizard *Sceloporus graciosus*	F, C
Side-blotched Lizard *Uta stansburiana*	X
Short-horned Lizard *Phrynosoma douglassi*	X, F
Western Skunk *Eumeces skiltonianus*	X
Southern Alligator Lizard *Elgaria multicarinatas*	X, F
Rubber Boa *Charina bottae*	X
Sharp-tailed Snake *Contia tenuis*	X
Racer *Coluber constrictor*	X
Striped Whipsnake *Masticophis taeniatus*	X
Gopher Snake *Pituophis melanoleucus*	X
Night Snake *Hypsiglena torquata*	X
Western Rattlesnake *Crotalus viridis*	X
BIRDS	
Turkey Vulture *Cathartes aura*	R, F
Sharp-shinned Hawk *Accipiter striatus*	F
Cooper's Hawk *Accipiter cooperii*	F
Red-tailed Hawk *Buteo jamaicensis*	R, F
Ferruginous Hawk *Buteo regalis*	R, F
Rough-legged Hawk *Buteo lagopus*	F
Golden Eagle *Aquila chrysaetos*	R, F
American Kestrel *Falco sparverius*	R, F
Prairie Falcon *Falco mexicanus*	R, F

C = Used for Cover, **F** = Used for Feeding, **G** = Game Species, **I** = Introduced, **R** = Habitat Used for Reproduction,
X = General community or habitat in which found

SPECIES	JUNIPER STEPPE
Chukar *Alectoris chukar*	I, G, R, F
Mourning Dove *Zenaida macroura*	G, R, F
Great Horned Owl *Bubo virginianus*	R, F
Northern Pygmy Owl *Glaucidium gnoma*	R, F
Burrowing Owl *Speotyto cunicularia*	R, F
Long-eared Owl *Asio otus*	R, F
Common Nighthawk *Chordeiles minor*	R, F
Common Poorwill *Phalaenoptilus nuttallii*	R, F
Rufos Hummingbird *Selasphorus rufus*	F
Northern Flicker *Colaptes auratus*	R, F
Dusky Flycatcher *Empidonax oberholseri*	R, F
Gray Flycatcher *Empidonax wrightii*	R, F
Ash-throated Flycatcher *Myiarchus cinerascens*	R, F
Western Kingbird *Tyrannus verticalis*	F
Horned Lark *Eremophila alpestris*	R, F
Tree Swallow *Tachycineta bicolor*	F
Violet-green Swallow *Tachycineta thalassina*	F
Northern Rough-winged Swallow *Stelgidopteryx serripennis*	F
Bank Swallow *Riparia riparia*	F
Cliff Swallow *Hirundo pyrrhonota*	F
Barn Swallow *Hirundo rustica*	F
Steller's Jay *Cyanocitta stelleri*	F
Pinyon Jay *Gymnorhinus cyanocephalus*	R, F
Black-billed Magpie *Pica pica*	R, F
Common Raven *Corvus corax*	R, F
Mountain Chickadee *Parus gambeli*	R, F
Rock Wren *Salpinctes obsoletus*	R, F
Canyon Wren *Catherpes mexicanus*	R, F
Mountain Bluebird *Sialia currucoides*	R, F
Townsend's Solitaire *Madestes townsendi*	F

C = Used for Cover, **F** = Used for Feeding, **G** = Game Species, **I** = Introduced, **R** = Habitat Used for Reproduction,
X = General community or habitat in which found

SPECIES	JUNIPER STEPPE
American Robin *Turdus migratorius*	F
Sage Thrasher *Oreoscoptes montanus*	R, F
Bohemian Waxwing *Bombycilla garrulus*	F
Cedar Waxwing *Bombycilla cedrorum*	F
Northern Shrike *Lanius execubitor*	F
Loggerhead Shrike *Lanius ludovicianus*	R, F
European Starling *Sturnus vulgaris*	I, R, F
Yellow-rumped Warbler *Dendroica coronata*	F
Black-throated Gray Warbler *Dendroica nigrescens*	R, F
Townsend's Warbler *Dendroica townsendi*	F
Green-tailed Towhee *Pipilo chlorurus*	R, F
Brewer's Sparrow *Spizella breweri*	R, F
House Finch *Carpodacus mexicanus*	R, F
Pine Siskin *Carduelis pinus*	F
MAMMALS	
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
Silver-haired Bat *Lasionycteris noctivagans*	X
Townsend's Big-eared Bat *Plecotus townsendii*	X
Pallid Bat *Antrozous pallidus*	X
Mountain Cottontail *Sylvilagus nuttallii*	X
Black-tailed Jackrabbit *Lepus californicus*	X
Yellow-pine Chipmunk *Tamias amoenus*	X
Least Chipmunk *Tamias minimus*	X
Golden-mantled Ground Squirrel *Spermophilus lateralis*	X
Townsend's Ground Squirrel *Spermophilus townsendii*	X
Great Basin Pocket Mouse *Perognathus parvus*	X
Ord's Kangaroo Rat *Dipodomys ordii*	X

SPECIES	JUNIPER STEPPE
Deer Mouse *Peromyscus maniculatus*	X
Pinon Mouse *Peromyscus truei*	X
Northern Grasshopper Mouse *Onchomys leucogaster*	X
Bushy-tailed Woodrat *Neotoma cinerea*	X
Common Porcupine *Erethizon dorsatum*	X
Coyote *Canis latrans*	X
Long-tailed Weasel *Mustela frenata*	X
American Badger *Taxidea taxus*	X
Mountain Lion *Felis concolor*	G, X
Bobcat *Lynx rufus*	F, X
Domestic Wild Horse (Feral) *Equus caballus*	I, X
Mule or Black-tailed Deer *Odocoileus hemionus*	G, X
Mountain (or Bighorn) Sheep *Ovis canadensis*	G, X

C = Used for Cover, F = Used for Feeding, G = Game Species, I = Introduced, R = Habitat Used for Reproduction, X = General community or habitat in which found.

(from Puchy and Marshal 1993)

during the winter was closely related to temperature, wind, snow cover and depth (Leckenby and Adams 1986). As the combination of these factors increased in severity fawn survival decreased. Deer used the juniper woodland communities more frequently during severe winter conditions. During the winter of 1967-1968 deer occupation of the juniper woodlands peaked during January when weather stress was greatest. In a juniper woodland with 30% tree cover 4.5 m (14.7 ft) tall, winter weather conditions were less severe 47% of the time than adjacent shrub communities.

Leckenby et al. (1982) defined optimal thermal cover for mule deer in the juniper zone as "stands of evergreen or deciduous trees or shrubs, as least 1.5 m tall, with crown closure greater than 75%. However, as the juniper canopy increases understory vegetation usually declines. A juniper woodland community with 30% tree canopy cover contained decadent shrubs and scarce forage (Leckenby and Adams 1986). Adams (1975) reported a large increase in juniper density from 1900 through the 1930s followed by a large decline in bitterbrush. On Steens Mountain, the majority of mountain big sagebrush and bitterbrush are dead or decadent in recently developed juniper woodlands where tree canopy cover is exceeding 30% (Eastern Oregon Agricultural Research Center data file).

During fawning in the spring on Steens Mountain, the most preferred habitat was in mountain big sagebrush with a canopy cover exceeding 23% , and >40% was the most preferred (Sheehy 1978). Although woodland communities were not preferred, the majority of fawning sites were within 50 m (164 ft) of an aspen grove or juniper woodland.

Although Maser et al. (1984) lists juniper/shrub/bunchgrass as one of the structural communities in which antelope feed, most references describe preferred antelope habitat as being open with low statured vegetation (Kindschy et al. 1982). Trainer et al. (1983) found little antelope use of juniper woodlands during the winter or spring in eastern Oregon. They found low sagebrush communities were the most preferred and western juniper the least preferred. Throughout their range, antelope prefer open communities with a low vegetation structure, averaging 38 to 60 cm (Kindschy et al. 1982).

Studies on interrelationships of Rocky Mountain elk with western juniper woodlands are unavailable. However, the advent of elk expansion in recent years into these woodlands as well as the sagebrush-steppe in Oregon warrants investigation. Also wild horses likely make use of juniper woodlands, but studies are not available.

Birds

Field studies of bird use in western juniper woodlands are very limited. Even throughout the pinyon-juniper ecosystem in the West avian ecologists have largely ignored this region (Sedgwick 1987). Species regularly occurring in western juniper woodlands, which is largely based on observations, is summarized in Table 12 (Puchy and Marshall 1993). Maser and Gashwiler (1977) conclude juniper woodlands are used most by birds at ecotones between sagebrush communities and where stands are isolated from other types of woodland communities. No reference to stand structure was made.

Juniper berries are readily consumed in the winter by the Townsend solitare (*Myadestes townsendii*) (Lederer 1977, Poddar and Lederer 1982), American robin (*Turdus migratorius*), Steller's jay (*Cyanocitta stelleri*), scrub jay (*Aphelocoma coerulescens*), (the first four species are likely primary vectors of juniper seed in the Great Basin) and mountain bluebirds (Solomonson and Balda 1977). Western juniper berries are the sole winter food used by Townsend solitares (Lederer 1977, Poddar and Lederer 1982). Ripe berries contain 5 kcal/g caloric content and 4% protein, 46% carbohydrate, and 16% lipid content (Poddar and Lederer 1982). In the pinyon-juniper zone Solitares consumed 240 Utah juniper berries/day and robins 220/day (Solomonson and Balda 1977). They also found densities of bluebirds seem closely related with berry density. Sage grouse are generally associated with low and big sagebrush communities for feeding, nesting, and loafing throughout the year (Call and Maser 1985, Gregg 1991, Willis et al. 1993). Wildlife biologists feel western juniper expansion into sagebrush bunchgrass communities will likely be detrimental for sage grouse habitat. A question that has not been addressed is the relationship between sage browse use and juniper density and height.

The relationship between removal of western juniper to bird densities and composition has had little attention. The first year following cutting with trees remaining on the ground, both total numbers and species of birds were about twice as great in the cut areas as compared to adjacent uncut sites (Eastern Oregon Agricultural Research Center data file). The majority of use in the cut woodlands occurred within the down canopies which still retained their needles. In the pinyon-juniper zone, bird densities declined in cleared treatments (O'Mera et al. 1981). However, in a pinyon-juniper woodland that was burned, both bird numbers and density increased (Mason 1981).

Small Mammals

Very little work has been done on the relationships between small mammals and juniper woodlands. Table 8 lists small mammals observed in juniper woodlands. In central Oregon small mammal populations in a newly cut juniper woodland were similar to adjacent uncut communities (Eastern Oregon Agricultural Research Center data file). Bat biologist, Mark Perkins, has observed the palled, woodland, Great Basin, and big-eared bat (currently a candidate species) in juniper woodlands; however, little is known about these species in the semiarid lands in eastern Oregon (personal communication). Several studies in the pinyon-juniper ecosystem have reported increases in small mammal populations following clearing if tree slash is left on the ground (Kundaeli and Reynolds 1972, O'Meara et al 1981, Severson 1986, Howard et al. 1987, Sedgwick and Ryder 1987).

Amphibians and Reptiles

As a group, probably the least is known about amphibian and reptile use of juniper woodlands. Observations of occurrence of this group in juniper woodlands are reported in Table 12.

Conclusions

The structure of plant communities containing juniper are highly variable, from open stands rich in shrubs, grasses and forbs, to dense juniper woodlands with little understory vegetation. The relationship between juniper density, understory composition, and structure with wildlife species is poorly defined. The lack of field studies has led to summarizations of animal species using juniper woodlands which is based primarily on observation supported by minimal data. We also know little about the effects of patch cutting or thinning juniper woodlands on wildlife use.

Conversion of Western Juniper Woodlands

Estimates provided from various sources including the Bureau of Land Management, County Extension Offices, and ASCS Offices indicate that less than 1,600 ha/yr (4,000 ac/yr) of western juniper woodland in Oregon, exclusive of National Forest Lands have been treated to control western juniper over the last 10 year period. Wildfire is not included in these estimates. Conversely, age class-area data, supplied by Oswald (1990), which is exclusive of National Forest lands, indicates a general rate of woodland expansion of about 7,000 ha/yr (18,000 ac/yr) in Oregon over the last three reported decades. However, expansion rates of stands roughly 30 years old or less were not reported.

Although a small percentage of the total juniper woodland has been treated under the auspices of some type of management program, research carried out in western juniper woodlands provides incomplete guidelines for selection of areas to be treated, proper treatment and best follow-up management practices. Therefore, guidelines have to be partially drawn from the general body of knowledge on semiarid woodland ecosystem operation.

Published papers on ecosystem response to control of western juniper fall into several categories including (1) chemical and other control mechanisms and understory response (Britton and Sneva 1981, Young et al. 1985, Evans and Young 1985, Evans and Young 1987, Rose 1989, Rose and Eddleman 1994, Vaitkus 1986, Vaitkus and Eddleman 1987); (2) revegetation efforts (Evans and Young 1987, Leckenby and Toweill 1983, Young et al. 1985); (3) response of overstory ponderosa pine (Rose 1989, Rose and Eddleman 1994); and (4) slash leachate effects (Ramsey 1989).

Chemical control of western juniper trees has been attempted, but with mixed results. Aerial applications of tebuthiuron pellets at 2 and 4 kg/ha (ai) on a western juniper/low sagebrush (*Artemisia arbuscula*) site resulted in very limited juniper mortality in eastern Oregon but drastically reduced all understory species at both application rates, except for cheatgrass and big sagebrush (Britton and Sneva 1981).

When the juniper trees are killed, large increases in production of understory vegetation occur (Evans and Young 1985,1987, Vaitkus 1986, Vaitkus and Eddleman 1987). Variation in response in these studies was related to the location, i.e. under canopy or in the interspace between canopies, initial canopy cover of juniper, species available, time for response and tree size.

In northeastern California studies by Evans and Young (1985, 1987), reported pretreatment herbaceous yields near 0 and 150 kg/ha for the beneath canopy zone and the interspace zone respectively. After treatment with picloram, fastest and greatest production response was at the canopy edge which peaked the fourth year after treatment at over 1,300 kg/ha and then declined. Other locations under the canopy as well as intercanopy areas were still increasing in production but appeared not to have peaked in production even after seven years. Intercanopy areas in juniper stands with lower canopy cover of 35% and high initial shrub cover (28%) showed less response to tree mortality. After 6 or 7 years, herbaceous production from the mid-canopy zone outward through the interspace had reached 1,000 kg/ha or more, with one exception of about 600 kg/ha.

Measurements of available moisture showed higher amounts available later into the season on treated plots compared to check plots (Evans and Young 1985). Total nitrogen in the 0 to 2.5 cm (0 to 1 in) soil zone was closely related to herbaceous production. There was a direct vegetational response as total soil nitrogen increased through time following treatment. Litter accumulation also played a role in slowing vegetation response at the tree base to mid-canopy zone, and litter decay was attributed a significant role relative to increasing total nitrogen in the soil over time.

The above study points to a significant problem where aggressive annual grasses are present. Perennial grasses were sparse and did not respond to the treatment. Rather cheatgrass came to dominate the canopy position. This plant increased rapidly in the intercanopy area however medusahead was increasing in the interspace zone and appeared to be replacing the annual brome near the end of the study. Groups of perennial herbaceous plants either did not respond to treatment or declined.

A central Oregon study by Vaitkus (1986) and Vaitkus and Eddleman (1987) found increases in herbaceous production to be species specific following removal of western juniper over a 2-year response period. Table 13 shows the relative difference in production on soils of different depths, and response to tree removal relative to position. Table 14 shows the response on an area basis. These figures show a release response but the expected peak and decline could not be determined in two years. Precipitation for both years was well above the 30 year average growth year precipitation, 44% and 21% for the first and second year, respectively.

Species which responded positively in production to juniper removal were squirreltail and cheatgrass (Vaitkus 1986, Vaitkus and Eddleman 1987). Annual forbs, perennial forbs and annual grasses other than the brome responded positively. Tree size influenced response of individual species. For large dominant trees, the sub-canopy zone tended to become dominated by cheatgrass and perennial and annual forbs. Smaller trees had less effect on species specific response. Also intercanopy areas showed less species specific response relative to tree size than the sub-canopy zone.

Western juniper has been expanding into the ponderosa pine zone in central Oregon and may be affecting growth rates of the pine. Response of understory plant biomass and cover and pine growth to western juniper removal were measured on two study sites near Prineville, Oregon (Rose 1989 and Rose and Eddleman 1994). Treatments

Table 13. Aboveground biomass production response to western juniper removal in central Oregon in 1984. Values are for the second year and only for trees with >5 m crown diameter.

	Shallow Soils (40 cm)		**Deep Soil (74 cm)**	
	Sub-canopy Zone	**Interspace Zone**	**Sub-canopy Zone**	**Interspace Zone**
	(kg/ha)*	**(kg/ha)**	**(kg/ha)**	**(kg/ha)**
Check	384	273	626	454
Trees Removed	1,165	636	1,350	983

* kg/ha x 0.893 = lbs/ac.

Table 14. Aboveground biomass production response to western juniper removal in central Oregon in 1983 and 1984. Values are weight for percent of area in each zone (sub-canopy and interspace) and include all size classes of trees.

Total Area Production (wted by Zone %) all size classes of trees

	Shallow Soils kg/ha	Deep Soils kg/ha
Year 1-check	415	496
Year 1-Trees Removed	679	750
Year 2-Check	250	420
Year 2-Trees Removed	720	990

(from Vaitkus 1986)

were made the summer and fall of 1984 and results measured in 1985 and 1986. In this study, combinations of juniper removal and pine thinning were used. When pine was thinned, an average of 5.5 m by 5.5 m (18 x 18 ft) spacing was used. Pretreatment juniper densities ranged from an average of 75/ha (30/ac) in one treatment up to an average 331/ha (135/ac) in another. Juniper basal areas ranged from an average of 1.2 m^2/ha (13 ft^2/ac) in one treatment up to an average of 9.6 m^2/ha (103 ft^2/ac) in another.

Juniper removal increased production of squirreltail, sandberg bluegrass, total perennial grasses and total grasses. Bluebunch wheatgrass ranged in production from 50 to 70 kg/ha (kg/ha x 0.893 = lbs/ac) and Idaho fescue from 20 to 40 kg/ha and appeared not to respond to juniper removal when analyzed individually. Average understory production for all juniper retained plots and juniper removed plots was 364 kg/ha and 474 kg/ha respectively in year one and 290 kg/ha and 442 kg/ha, respectively, in year two (Rose 1989 and Rose and Eddleman 1994).

Basal area growth of ponderosa pine over the first two years following treatment was not affected by juniper removal except for those pines with basal diameters of less than 5 cm (2 in) and these were negatively affected by juniper removal (Rose 1989 and Rose and Eddleman 1994). Lack of response of pine in the larger size classes may have been due to a lag time in response while trees were adjusting foliage and root systems.

Stand conversion is a process in western juniper woodlands that includes control of individual trees across a landscape. Control and harvest practices may need to be such that mineral deficient sites are least impacted by tree removal. Larger and presumably older trees have been sequestering minerals in their tissue over many years. The distribution of minerals in tree roots and tops may influence the control practices used.

Table 15 represents a biomass and mineral estimate by tissue groups for western juniper trees in central Oregon. Mineral concentrations in tissue types are from Miller et al. (1990), aboveground biomass from Larsen (1993), and root estimates from Kramer (1990).

The tree characterized is an average dominant western juniper tree which is 11 m (36 ft) tall, has a basal diameter above root swell of 44 cm (17 in), and a canopy diameter of 7 m (23 ft).

According to these data, foliage tissue has the highest concentrations of N and K while fine roots have highest concentrations of P, Ca, and Mg. Bole removal would represent roughly one-third of the aboveground biomass removed but less than 30% of the sequestered nitrogen. Removal of this whole tree and transport off-site would roughly equal a site loss of 2.8 kg of nitrogen, 0.8 kg of phosphorus, 1.5 kg of potassium, 6.8 kg of calcium, 0.5 kg of magnesium per tree removed. Left belowground would roughly be 0.7 kg of root nitrogen and about 4.6 kg of other root tissue minerals for this tree.

Table 15. Estimated biomass and mineral content of a western juniper tree 11 meters (36 ft) tall with a basal diameter of 44 cm (17.3 in).

	Biomass		**Mineral Content in Grams**[4]				
	(kg)[3]	**% of Ag**	**N**	**P**	**K**	**Ca**	**Mg**
Foliage	72	15	900	190	520	1,060	140
Branch	237	51	1,160	360	570	3,410	190
Bole	158	34	770	240	380	2,280	130
Ag Total[1]	**467**	**100**	**2,830**	**790**	**1,470**	**6,750**	**460**
Fine Roots	16	3	120	150	80	1,840	60
Coarse Roots	166	36	510	310	270	1,810	130
Bg Total[2]	**182**	**39**	**730**	**460**	**350**	**3,650**	**190**
Tree Total	**649**	**139**	**3,460**	**1,250**	**1,820**	**10,400**	**650**

[1] Ag = aboveground.
[2] Bg = belowground.
[3] kg x 2.205 = lbs.
[4] grams/454 = lbs.

(from Larsen 1993, Kramer 1990, and Miller et al. 1990)

The western juniper tree characterized above is usually in the 80 to 90 year old age class. Growth rate, in terms of incremental increases in biomass of the various plants parts, is not known but is probably exponential to this age. If the information on growth were available then estimates of yearly nutrient withdrawal from the soil system could be made. A simple division of biomass by the tree age would yield an overestimate of yearly biomass increase for young trees and an underestimate for older trees.

Revegetation is frequently used in western juniper woodlands either to provide seasonal forage (Leckenby and Toweill 1983) or to replace or prevent annual grass dominance (Young et al. 1985, Evans and Young 1987).

Lechenby and Toweill (1983) used two seeding treatments, chain - drill and drill, on six western juniper subtypes in northwestern Lake County, Oregon. Seeding mixtures were made up of seven to eight plant species composed of grasses, forbs and shrubs. Grass species seeded included crested wheatgrass (*Agropyron desertorum*), Siberian wheatgrass (*A. sibericum*), smooth brome (*Bromus inermis*) and basin wildrye (*Elymus junceus*). Forb species seeded were alfalfa (*Medicago sativa,)* small burnet (*Sanguisorba minor*), sainfoin (*Onobrychis viciaefolia*), and clear milkvetch (*Astragalus cicer*). Shrub species seeded were big sagebrush, 4-wing saltbush (*Atriplex canescens*), and bitterbrush.

Emergence the first year ranged from 4 to 20%. Establishment success was limited to the two wheatgrasses, with all other species collectively averaging less than 2 plant per m^2. Chain-drill treatments produced greater densities of wheatgrasses over drill only. One juniper subtype, douglas sedge, negatively affected emergence.

Young et al. (1985), in northeastern California, used three tree control methods, picloram and limb, wood harvest and mechanical removal. When slash was created, it was allowed to dry and was then burned. Herbicidal control of brush and herbaceous weeds was followed by reseeding with a rangeland drill using intermediate wheatgrass (*Agropyron intermedium*) 'Greenar', alfalfa (*Medicago sativa*) 'Ladak' and Sainfroin 'Eski'. Sheep fescue (*Festuca ovina*) 'Covar' and canby bluegrass (*Poa canbyi*) 'Canbar" were also seeded. Two year old seedlings of bitterbrush, mountain mahogany (*Cercocarpus ledifolius*), and 4-wing saltbush were transplanted into some treatments.

Only intermediate wheatgrass and alfalfa established well in the mechanically cleared plots. They did not exceed production of annual grasses until the fourth year. Where weed free conditions existed on the wood harvest and the picloram-limb treatments, this due to herbicidal control or the presence of ash seedbeds, the above two species established well. Tree litter provided an undesirable seedbed for seeded species and these areas became occupied by annual grasses.

Ramsey (1989) evaluated the effects of fresh green slash and one year old red slash leachates on germination of bluebunch wheatgrass and emergence and growth of bluebunch wheatgrass, big bluegrass (*Poa ampla*), and Indian ricegrass (*Oryzopsis hymenoides*).

Leachates did not affect either germination rate or total germination in bluebunch wheatgrass. Leachates did not affect emergence but generally inhibited growth of all species, red slash being most inhibitive. Indian ricegrass was least affected while big bluegrass was most affected. Root biomass, shoot biomass and tiller numbers were markedly reduced by red slash leachate. Ion concentration in both leachates dominated by calcium, phosphorus, potassium, magnesium and sodium. Analysis revealed four phenolic compounds in the red slash and none in the green slash. These phenolics may have interfered with physiological processes and reduced growth.

Revegetation research in western juniper woodlands is limited in many respects. Particularly critical missing elements are those dealing with:

1. restoration of native species including the shrub component,
2. revegetation for watershed health,
3. critical threshold densities of desirable species below which seeding is needed,
4. methodologies of revegetating systems which are effective and cost efficient without loss of resources from the site,
5. relationships of managed western juniper densities or canopy cover to seeding and establishment success with particular reference to restoration of vegetation and watershed health with juniper retained in the system.

Grazing Management of Western Juniper Woodlands

Grazing management in the western juniper woodlands can and should be based on watershed and plant growth objectives.

Firstly grazing management should be focused on three highly interrelated goals which seek to maintain or improvement on-site watershed health and function and including:

1. those which allow the site to capture water, i.e. high infiltration rates and high capacity surface detention storage;

2. those under which effective water storage occurs, i.e. high soil organic matter and well dispersed litter and plant canopies to reduce evaporation losses; and

3. those in which the release of water from the site result in low sediment transport in runoff, and in subsurface flow and plant use. In this case, potential use of water in plant physiological processes is promoted and the evaporative process taking place at the soil surface is restricted.

Secondly grazing management should be focused on goals which seek to maintain or improve on-site vegetation health, function and biodiversity including:

1. those which allow plants to capture sufficient resources, i.e. photosynthetically active leaf area and an active root system;

2. those which allow storage of resources and plant growth, i.e. root, crown and stem resource storage for drought survival, overwintering and new growth initiation; and

3. those which retain sufficient canopy cover and litter to protect the plant from mortality or less of vigor during stress times. In this latter case, storage of resources below ground as in bulbous forbs may require little canopy or litter while others such as some grasses which store resources near the soil surface may require both a canopy and litter cover.

On-site vegetation health and function goals are also highly interrelated with each other and with the goals listed above for watershed health and function.

Historically livestock grazing tended to take place in the spring as domestic animals moved from lowlands through intermediate elevation range, which was the juniper woodlands and associated sagebrush-grass communities, to higher mountain summer range. In some areas, domestic animals grazed back through the woodland in the fall or were held in the woodlands during this season if water and forage were adequate. In other cases, higher elevation range was not available and grazing animals used the woodland areas when water was available, which in some cases, this was winter, spring, and up to yearlong.

Grazing management of western juniper woodlands has not been addressed by researchers. Most research relative to grazing in western juniper woodlands as well as pinyon-juniper woodlands falls in the area of improvement in herbaceous cover and forage production through non-grazing treatments, i.e. pinyon-juniper control, and restoration of plant species or functional groups of plants for livestock and mule deer use. Grazing management in the western juniper woodlands is not however entirely in the speculative realm; however, one can draw upon biological, physiological and ecological research which has been completed in the woodlands, plus research on plant response to herbivory.

There are two major resource situations, each with several subsets of conditions, under which grazing management needs to be evaluated. These are grazing management in woodlands and grazing management following juniper control. A third situation, grazing management on sites susceptible to western juniper expansion, will be dealt with briefly. Goals previously listed apply to all three situations.

In the planning process, goals and objectives developed from those goals, must be completed prior to development of grazing guidelines or prescriptions. In this discussion, guidelines are used because they imply less rigidity. In the implementation process the goals developed in the planning process should change little. Objectives may be altered or changed as the ecosystems respond to applied management and as certain needs change. Goals and objectives should always take precedence over guidelines or prescriptions, because guidelines are intended only to meet established goals and objectives and should be adjusted for changing conditions of vegetation and soil as well as kinds of use.

- Grazing recommendations given below are conservative and in many cases represent a worst-case scenario, that is a closed stand of western juniper trees.

- When a condition exists such as an open woodland, a good condition understory vegetation, a moist site or a relatively high precipitation, situation then the amount of grazing use can be higher than that suggested below.

- Judiciously adapting grazing management strategies to the ecological site, to variables of overstory-understory conditions, and to variations in seasonal and year-to-year precipitation will also allow higher levels of use than suggested below.

Grazing Young Woodlands

Grazing management in western juniper woodlands must take into account the actual grazeable area. It is important to recognize that areas occupied by juniper have their grazeable area reduced roughly proportional to the canopy cover of the juniper trees due to limited accessibility below the lower canopy branches and altered plant production and composition under the tree. A 40% canopy cover therefore leaves about 60% of the area for grazing by domestic livestock. Exceptions may exist in old woodlands where the older trees have lost their lower branches, however these old trees have tended to build up a thick needle litter mat which eliminates or restricts understory vegetation.

In young woodlands the successional process of gaining dominance by western juniper is still ongoing. Juniper density and cover are increasing in uneven-aged stands while in even-aged stands only canopy coverage is increasing. These processes of expansion and dominance have not reached their potential in most woodlands so that equilibrium with other plant species has not been achieved. It may well be that western juniper can reach sufficient densities and cover on certain sites to the extent that whole groups of understory plant species, including productive forage species, will be essentially eliminated, even without grazing.

The transitional nature of these young woodlands plus the multitude of potential successional states possible on the wide range of sites where they grow create real problems in developing static grazing management guidelines. Therefore guidelines should revolve around sustaining or improving site productivity based on plant production and storage of plant available water in the soil profile.

Grazing Management of Young Closed Western Juniper Woodlands on Shallow Soils

OBJECTIVES
1) High vigor forage plants
2) High understory plant canopy spread
3) Plants well dispersed across the site
4) High litter cover and dispersion

GUIDELINES
1) Light utilization as plants near maturity,
2) or Light utilization after maturity;
3) Repeated light use during late growth period only in years having regular effective precipitation inputs during the effective growth period.*

* Caution is needed here since we do not know the most effective precipitation input time or interval for sustaining plant growth at the species level in the western juniper woodland. Time and interval is likely different among major forage species, e.g. Thurber's needlegrass, Idaho fescue and bluebunch wheatgrass, and perhaps even greater differences exist in other associated grasses, forbs, and shrubs.

Rationale

Grazing management will need to account for soil water available for plant use both spatially and temporally. Western juniper intercepts precipitation falling on its canopy and subcanopy litter layer and uses stored soil water from the areas between canopies prior to understory plant growth, during growth periods of understory plants, and during summer dormancy if precipitation inputs occur. Where conditions such as shallow soils or dry years exist, low amounts of precipitation are stored in the soil and plant available water for understory growth becomes limiting in both amount and duration. Shallow soil and dry conditions are common in western juniper woodlands. Grazing during the growth period of forage plants under such conditions is hazardous because loss of plant vigor, plant density and ground cover is likely to occur.

Forage plants are restricted by limited water and nutrient resources due to interference from juniper roots and are further limited in their ability to maintain a nutrient and energy resource pool if grazed during their period of resource acquisition. One probable scenario is that feeder roots of juniper which occupy the zone below grass crowns are absorbing nutrients being cycled in the main root zone of the grass plant. Dead grass roots produced in previous years or as the result of heavy grazing during the current growth period as well as death of root hair, provide substrate for microbial cycling of nutrients. These nutrients are accessed by juniper roots over a period of several months both in the year grazed and in the following year prior to and during herbaceous growth. However, grazed grass plants may have a short period of 3-4 weeks to absorb these nutrients, or if regrowth does not occur, it must wait for the following year. Absence of regrowth may be due to low plant available soil moisture, low plant available nitrogen or low plant vigor.

The abundance of dead and dying sagebrush, a plant usually not grazed at all, on young developing woodland sites with shallow soils serves to indicate the severity of soil moisture and nutrient interference by western juniper. However not all woodland sites have significant amounts of sagebrush present. Furthermore, deep soils may also have an abundance of dead and dying sagebrush.

Grazing during early growth would appear to be particularly damaging to understory plant vigor since the window of moisture and nutrient availability is short and likely optimal only early in the growth period. The window however may be extended by continued effective inputs of precipitation during the months of April, May and June.

Light grazing when forage plants are reaching maturity may result in non-significant reductions in vigor, but "light" would be on the order of 10% to 15% utilization.

Resting grazed areas for 1 to 2 years after moderate to heavy use to allow recovery is a common practice. Where forage plants face strong interference from western juniper, a probable threshold is any canopy cover of juniper above 20%, it seems very doubtful that rest from grazing for 2 to 3 years would allow full recovery. Rather, during the grazed period juniper will incrementally gain further site dominance and restrict recovery during ungrazed periods.

Rest may be an important factor in a grazing prescription when coupled with wet years. Plant vigor gains and increased reproduction in understory species may result.

Grazing following plant maturation may or may not be acceptable. Several limitations exist, which relate to the hydrologic cycle primarily but not exclusively.

If grazing is too heavy, understory plants become ineffective insulators against soil temperature fluctuations and moisture evaporation from the soil surface. As previously noted the microenvironment of the western juniper woodland during the winter is relatively warm with snow cover of short duration. Wet soil surfaces, without plant or snow insulation, between tree canopies can be expected to develop concrete frost during the colder part of the winter and to diurnally freeze and thaw in late winter and early spring. Infiltrability of concrete frost is essentially zero and results in precipitation runoff. Freeze-thaw activity pulls water to the soil surface where it is subject to evaporation.

During warm winter periods, when soil is unfrozen, surface evaporation of moisture takes place. In the top 50 mm (2 in) and in some cases down to 70 mm (2.7 in) of the soil surface. About 16 mm (0.6 in) of stored precipitation is required to bring the surface 50 mm of soil back to field capacity; less is required if the surface is gravelly or stony. Thus, potential evaporation from exposed soil surfaces could be as high as 16 mm for a single storm event depending on temperatures, days between storm events and storm size. The majority of precipitation events in the western juniper woodland are less than 16 mm. When these processes are prevalent on shallow soils with inherently low water storage capacity, soil water storage and water available for plants can be markedly reduced.

Plant and litter cover are the only insulation factors grazing management can control in a major way. Other factors such as days with snow cover are few and unpredictable and rock or gravel cover vary with site.

Some shallow soils, particularly those associated with low sagebrush, may become saturated during the winter period. Once saturation is reached runoff will occur from added inputs of precipitation or from snow melt. Plant cover and dispersion as well as litter will reduce sediment transport to lower areas.

The following questions need to be answered in order to apply appropriate guidelines to western juniper woodlands.

What is a shallow soil?

A shallow soil can be considered one for which the effective depth is equal to or less than equal to the potential depth of the main root mass of the larger perennial bunchgrasses. Generally this will be soils less than 30 cm (12 in) deep. A high clay content in the lowest horizon may partially compensate for the inherent droughtiness in a shallow soil. Fractured bedrock below the soil will partially compensate by allowing juniper rooting at depth, thus make it less competitive with understory plants for moisture.

What is a dry year?

A dry year on a woodland site is one in which winter moisture is stored no deeper than 30 cm and in which regular effective inputs of precipitation (>16 mm~) are largely absent during growth initiation and during the optimal growth period of herbaceous plants. Moisture stored over the winter period is marginally effective for understory plant growth because the amount of moisture stored in shallow soils is low and that which is stored can be largely depleted by western juniper prior to active herbaceous plant growth.

What is a closed stand of western juniper?

There is no research to help define the relationship of canopy cover to interference with understory plant growth. General observations indicate that there is severe interference to a distance equal to the height of the crown for mature trees. Since most dominant trees in young woodlands are about 10 m (33 ft) tall severe interference over an entire hectare could be achieved by about 32 trees/ha (13/ac) well under most density values reported above. For example, Evans and Young (1985) reported 150 trees/ha (61/ac) with an average height of 9.2 m (30 ft) in northeastern California.

How much herbaceous plant cover should remain after grazing?

The amount of residual herbaceous plant material, canopy and litter, to leave on the site is difficult to evaluate. These residuals should be high during significant runoff and sediment-producing periods, such as during high precipitation events, usually in May and June, and during late winter snow thaw both on-site and from runoff from adjacent slopes. Plant cover should also be high during low precipitation events to restrict rapid evaporation from the surface 50 mm of soil. Plant material cover should be high during periods of potential development of concrete frost and periods of potential freeze-thaw action in the soil surface to increase infiltration and reduce evaporation.

The objective of grazing therefore should be the retention of the herbaceous plant canopy's horizontal spread. From a utilization standpoint this could be achieved by only light grazing of 15% to 25% depending on the morphology of the species under use.

Grazing Young Western Juniper Woodlands on Deep Soils

OBJECTIVES
1) High vigor forage plants
2) Sustained growth during the growing season
3) High understory plant canopy spread
4) Plants well dispersed across the site
5) High litter cover and dispersal across the site.

GUIDELINES
1) Light utilization as plants near maturity,
2) or Light utilization after maturity,

3) Repeated light use during late growth period only in years having regular effective precipitation inputs during the effective growth period.

Nearly all comments relative to shallow soil conditions are applicable under deep soil conditions. The major differences are that greater amounts of available moisture for plant growth can potentially be stored in a deep soil and western juniper can root deeper and may interfere less with water and nutrient acquisition by herbaceous plants.

The advantages that deeper soils have over shallow soils include the potential for greater biomass production of understory plants and greater potential for regrowth and plant recovery from grazing. For these advantages to be realized, greater amounts of moisture must be stored in the soil profile and forage plants must have the opportunity to utilize both soil moisture and nutrients.

Detention of surface water, absence of concrete frost and dispersion of plant biomass over the site all contribute to storage of water in the soil profile. Healthy understory plants with good canopy spread promote all three conditions. Maintenance of these conditions may negate the practice of grazing heavy after plant maturity. Rather grazing utilization should be adjusted to promote adequate ground cover during the winter water storage period.

When good soil moisture storage during the winter occurs, additional precipitation during the spring months can sustain plant growth over relatively long periods of time. Under these conditions it should be possible to make successive light removals of herbage without adversely affecting either plant vigor or its nutrient pool. Utilization of herbaceous plants sufficiently heavy to force long delays in continued growth creates the probability of increasing interference by western juniper and should be avoided.

Under the grazing guidelines above, bitterbrush as well as other shrubs and forbs would seldom be grazed excessively and annual grasses would be little advantaged in competing with perennial forage grasses.

The guidelines above relate to areas which still support a good component of forage grasses. On areas where these grasses are declining not only light use as well as significant periods of rest may be needed. Rest may be most effective during wet years for producing maximal recovery of forage species.

If conditions have reached the point where forage plants are essentially eliminated and much of the soil is unoccupied by vascular plants then there is no acceptable grazing prescription other than non-use. At the same time there should be little expectation for recovery of a good understory in the absence of grazing.

When perennial forage plants are absent but the understory is fully occupied by cheatgrass or medusahead, grazing guidelines should be designed to maintain the best possible watershed health until such time as treatment and improvements in vegetation and watershed health can be achieved. Grazing these annual grasses should be directed toward maintaining an adequate plant cover to restrict sediment loss from the site during periods of potentially high runoff.

Grazing Management Following Western Juniper Control

When western juniper is removed or killed, all the understory plants respond to that release. Most studies indicate that a species specific peak in herbaceous vegetation response occurs in 2 to 3 years after release from juniper competition. This is followed by a decline to a lower level of annual productivity which is usually well above that of pretreatment conditions for the released species. Response time may peak later for sites in poor or fair vegetation condition where whole suites of species may need to establish new populations.

Unlike situations with closed stands of western juniper, the post treatment plant growth is not restricted to a narrow window of time and the probability of regrowth is much higher. Many observations indicate herbaceous plant growth to be continuous spring, summer, and fall the first and second year following juniper control. Even so, a grazing intensity which **requires** the formation of new tillers and leaves that are needed to carry on photosynthesis should be avoided.

Grazing guidelines employed under conditions where juniper is controlled must incorporate goals of vegetation composition as well as plant vigor and site productivity. Allowing time for recovery of vigor, key species to set seed and their seedlings to establish should be an integral part of any guideline. Under these conditions grazing should be regulated by monitoring and adjustment to achieve goals rather than by application of fixed guidelines and practices.

The initial control of western juniper should be seen as having a relatively short life, certainly not as a permanent conversion. In uneven-age stands, there may be as many as 10 seedlings and juveniles for every large tree killed. These small trees can be expected to respond to release along with other understory vegetation and over a period of time return the site to juniper dominance. Both even-aged and uneven-aged young woodlands may have a bank of western juniper seeds in the system which will germinate over time and lead site dominance back to juniper. Therefore follow-up management and future treatments such as burning, will be needed to maintain the area in a non-woodland condition.

OBJECTIVES 1) Rapid site dominance by desired understory species
2) High vigor desired forage plants
3) Sustained growth of desired plants during the growing season
4) High understory plant canopy spread
5) Plants well dispersed across the site
6) High litter cover and dispersal across the site.

These objectives apply to each of the four conditions listed below.

GUIDELINES

Good understory vegetation at the time of juniper control:

1) Non-use in first post treatment growth year and defer grazing until seed set the second growth year.

2) Repeated light use, rest, rotated seasonal use and deferred use are possibilities as long as plant vigor and watershed health goals and objectives are met.

Fair understory vegetation at the time of juniper control:

1) Non-use first and second post treatment growth year and defer grazing until seed set the third growth year.

2) Repeated light use, rest, rotated seasonal use and deferred use all are possibilities as long as plant vigor and watershed health goals and objectives are met.

Poor understory vegetation at the time of juniper control:

1) Non-use through plant vigor recovery, reproduction and seedling establishment phase, possibly 3 to 4 years.

2) Single or repeated light use as plant growth approaches maturity or light use after maturity until site reaches the objective set for its vegetation and watershed, possibly an additional 2 years.

3) Repeated light use, rest, rotated seasonal use and deferred use all are possibilities as long as plant vigor and watershed health goals and objectives are met.

Seeded areas

1) Non-use through seedling establishment phase, and attainment of a competitive population, possibly 2 to 4 years.

2) Single or repeated light use as plant growth approaches maturity or light use after maturity until site reaches the objective set for its vegetation and watershed, possibly an additional 2 years.

3) Repeated light use, rest, rotated seasonal use and deferred use all are possibilities as long as plant vigor and watershed health goals and objectives are met.

Adjustments in guidelines will be needed as treatments vary. Whole-tree removal, cut-and-leave whole trees, cut-and-slash scatter and the variable uses of fire all impact guidelines differentially. Variation in guidelines according to site and vegetation composition are to be expected.

The above guidelines are for arriving at a competitive and productive desired plant community as rapidly as possible. Avoiding a rapid buildup or dominance of undesired species, such as cheatgrass and medusahead or other recently introduced weedy species, is important for effective treatment life. Any grazing activity which increases the competitive edge of these species should be avoided.

Grazing Management on Sites Susceptible to Western Juniper Encroachment and Dominance

Goals listed previously all apply to grazing in situations where western juniper is likely to invade and dominate the ecosystem. However, there are additional objectives here that should be taken into account which affect juniper seed dispersal and the occurrence of sites suitable for juniper establishment. These objectives should include: 1) maintain a strong grass cover to restrict surface flow of water during natural seed dispersal periods and 2) keep big sagebrush densities as low as possible.

The first objective is to prevent rapid dispersal of juniper seed from up-slope sites across the area. During the late fall, winter and early spring period good surface water detention and avoidance of large patches of bare soil where concrete frost can form are important for restricting dispersal of western juniper seed.

The second objective is to limit the density of sagebrush because this shrub provides a safe establishment site for western juniper seedlings, and to develop a vigorous herbaceous component of the plant community to compete with seedlings of sagebrush and juniper that do become established. It may be important to include sagebrush control measures in some situations in order to reduce sagebrush densities to a reasonable level.

BIBLIOGRAPHY

Adams, A.W. 1975. A brief history of juniper and shrub populations in southern Oregon. Res. Div. Oreg. Wildlife Com. Wildl. Res. Rep No. 6. 33 pp. Oreg. Game Comm. Res. Rpt. P.R. Proj. W-53-R.

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington, D.C.

Anderson, D.C., K.T. Harper, and R.C. Holmgren. 1982. Factors influence development of cryptogamic soil crusts in Utah deserts. J. Range Manage. 35(2):180-185.

Anderson, E.W. 1956. Some soil plant relationships in eastern Oregon. J. Range Manage. 9:171-175.

Anderson, H.W. 1947. Soil freezing and thawing as related to some vegetation, climatic, and soil variables. J. For. 45:94-101.

Angell, F.F., and R.F. Miller. 1985. Water use by western juniper - A preliminary model. pp 31-36. **IN**: Agric. Exp. Sta. Spec. Rpt. 743. 1985 Progress Report. Research in Rangeland Management. Oregon State University, Corvallis, OR.

Angell, R.F., and R.F. Miller. 1994. Simulation of leaf conductance and transpiration in *Juniperus occidentalis*. For. Sci. 40(1):5-17.

Antevs, E. 1938. Rainfall and tree growth in the Great Basin. Carnegie Instn. of Wash., Publ. 469, Am. Geogr. Soc., Spec. Publ. 21.

Antevs, E. 1948. Climatic changes and pre-white man. pp. 168-181. **IN:** The Great Basin; with emphasis on glacial and postglacial times. Bulletin. University of Utah Biological Service 10(7).

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

Arnold, S.R., D.A. Jameson, and E.H. Reid. 1964. The pinyon-juniper type of Arizona: Effects of fire, grazing and tree control. U.S. Dept. Agric. Proj. Res. Rep. 84. 28 pp.

Art, H.W., and P.L. Marks. 1971. A summary of biomass and net annual primary production in forest ecosystems of the world. In: H. E. Young (ed.). Forest biomass studies, Univ. Maine Press. Orono.

Austin, D.D., and P.J. Urness. 1976. Small mammal densities related to understory cover in a Colorado Plateau, pinyon-juniper forest: Proc. Utah Acad. of Sci., Arts and Letters. 53/PT.1/5-12. Utah Division of Wildlife Resources.

Baker, M.B. Jr. 1982. Hydrologic regimes of forested areas in the Beaver Creek watershed. USDA, For. Serv. Rocky Mtn. For. and Range Exp. Sta. Ft. Collins, CO.

Baker, M.B. Jr. 1984. Changes in streamflow in an Herbicide-Treated Pinyon-Juniper Watershed in Arizona. Water Resources Research 20:1639-1642.

Baldwin, E.M. 1981. Geology of Oregon. Kendall/Hunt. Delbuque, Iowa.

Ball, J.T. 1987. Calculations related to gas exchange. In: Stomatal function. E. Zeiger,G.D. Farquhar, and I. R.Cowan (Eds.). Stanford Univ. Press, Stanford, CA. pp. 445-476.

Barney, M.A., and N.C. Frischknecht. 1974. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. J. Range Manage. 27:91-96.

Barrett, H. 1984. Western juniper and the range site concept. pp. 23-26. **IN:** Oregon State University Extension Service. Proceedings - Western juniper management short course. Oct. 15-16. Bend, OR.

Barth, R.C. 1980. Influence of pinyon pine trees on soil chemical and physical properties. Soil Sci. Soc. Amer. J. 44:112-114.

Bates, C.G., and A.J. Henry. 1928. Forest and streamflow experiment at Wagon Wheel Gap, Colorado. Final report on completion of the second phase of the experiment. Mo. Weather Rev. Supp. 30:79-85.

Bazzaz, F.A., K. Garbutt, and W.E. Williams. 1985. Effects of increased atmospheric carbon dioxide concentration on plant communities. Pages 155-170 in B.R. Strain and J.D. Cure, eds. Direct effects of increasing carbon dioxide on vegetation. US Dept. of Energy, DOE/ER-0238.

Bedell, T.E. (compiler). 1984. Proceedings - western juniper short course. Oregon State University Extension Service, Oct. 15-16, 1984. Bend, OR.

Bedell, T.E., and T.R. Bunch. 1978. Effects of western juniper on forage production and livestock grazing management. pp. 163-167. **IN:** Martin, R.E., J.E. Dealy, and D.L. Caraher (eds). Proc. West. Juniper Ecol. and Mange. Workshop. Bend OR. 1977. USDA For. Ser. Gen. Tech. Rpt. RNW-74.

Bedell, T.E., L.E. Eddleman, T. Deboodt, and C. Jacks. 1993. Western Juniper: Its impact and management in Oregon rangelands. EC 1417, Oregon State Extension Service, 15 pp.

Bedwell, S.F. 1973. Fort Rock Basin Prehistory and Environment. University of Oregon Books, Eugene, Oregon.

Belnap, J. 1993. Recovery rates of cryptobiotic crusts: Inoculant use and assessment methods. Soil. Biol. Biochem. 16(2):133-137.

Beymer, R.J., and J.M. Klopatek. 1991a. Effects of grazing on cryptogamic crusts in pinyon-juniper woodlands in Grand Canyon National Park. Amer. Midl. Nat. 127:139-148.

Beymer, R.J., and J.M. Klopatek. 1991b. Potential contribution of carbon by microphytic crusts in pinyon-juniper woodlands. Arid Soil Res. and Rehab. 5:187-198.

Blackburn, W.H. 1973. Infiltration rate and sediment production of selected plant communities and soils in five rangelands in Nevada. Agr. Exp. Sta., Univ. of Nevada-Reno. Rpt. 92.

Blackburn, W.H., and C.M. Skau. 1974. Infiltration rates and sediment production of selected plant communities in Nevada. J. Range Manage. 27:476-480.

Blank, R.R., and J.A. Young. Biological research needs for utilization of biomass from western juniper woodlands in conjunction with range improvement of privately owned rangelands. USDA, Ag. Res. Serv., Reno, NV.

Bolsinger, C.L. 1989. California's western juniper and Pinyon-juniper woodlands: Area, stand characteristics, wood volume, and fence posts. USDA, For.Ser. Resource Bull. PNW-RB-166.

Bright, L. 1978. Weather stress difference between two levels of juniper canopy cover. pp. 91-95. **IN:** Martin, R.E., J.E. Dealy, and D.L. Caraher (eds). Proc. West. Juniper Ecol. and Mange. Workshop. Bend OR. 1977. USDA For. Ser. Gen. Tech. Rpt. RNW-74.

Britton, C.M., and F.A. Sneva. 1979. Effect of tebuthiuron on a western juniper community. pp. 10-13. **IN:** Proc. Rpt. Res. in Beef Cattle Nutrition and Mgmt. Spec. Rpt. 534, Agric. Exp. Sta., Oreg. State Univ. Corvallis.

Britton, C.M., and F.A. Sneva. 1981. Effects of tebuthiuron on western juniper. J. Range Manage. 34:30-32.

Brotherson, J.D., and S.T. Osayande. 1980. Mineral concentrations in true mountain mahogany and Utah juniper, and in associated soils. J. Range Manage. 33:182-185.

Brotherson, J.D., and S.R. Rushforth. 1983. Influence of cryptogamic crusts on moisture relationships of soils in Navajo National Monument, Arizona. Great Basin Nat. 43(1):73-78.

Brotherson, J.D., S.R. Rushforth, and J.J. Johansen. 1983. Effects of long-term grazing on cryptogam crust cover in Navajo National Monument, Arizona. J. Range Manage. 36:579-581.

Buckhouse, J. 1984. Characteristics of watershed occupied by western juniper. pp. 46-47. **IN:** Oregon State University Extension Service. Proceedings - Western juniper management short course. Oct. 15-16. Bend, OR.

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

Buckhouse, J.C., and G.F. Gifford. 1976. Sediment production and infiltration rates as affected by grazing and debris burning on chained and seeded pinyon-juniper. J. Range Manage. 29:83-85.

Buckhouse, J.C., and J.L. Mattison. 1980. Potential soil erosion of selected habitat types in the high desert region of central Oregon. J. Range Manage. 33:282-285.

Bunch, T.R. 1984. Follow-up — Western juniper management. pp. 95-98. **IN:** Oregon State University Extension Service. Proceedings - Western juniper management short course. Oct. 15-16. Bend, OR.

Bunderson, E.D., D.J. Weber, and J.N. Davis. 1985. Soil mineral composition and nutrient uptake in *Juniperus osteosperma*. Soil Sci. 139:139-185.

Bunting, S. 1984. Prescribed burning of live standing western juniper and post-burning succession. pp. 69-73. **IN:** Oregon State University Extension Service. Proceedings -Western juniper management short course. Oct. 15-16. Bend, OR.

Bunting, S.C. 1987. Use of prescribed burning in juniper and pinyon-juniper woodland. pp. 141-144. **IN:** Everett, R.L. (compiler). Proceedings Pinyon-Juniper Conference, US For. Serv. Gen. Tech. Rpt. INT-215.

Burkhardt, J.W. 1969. Western juniper invasion in southwestern Idaho: an analysis of cause. Res. Pap. INT-238. 22 pp.

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

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

Call, M.W., and C. Maser. 1985. Wildlife Habitats in managed rangelands - the Great Basin of southeastern Oregon: sage grouse. USDA For. Serv. Gen. Tech. Rep. PNW-187.

Campbell, G.S. 1986. An introduction to environmental biophysics. Springer-Verlag, New York, NY. pp 159.

Caraher, D.L. 1978. The spread of western juniper in central Oregon, pp. 3-8. **IN:** Martin, R.E., J.E. Dealy and D.L. Caraher (eds.), Proc. Western juniper ecology and management workshop. Bend, OR. 1977. USDA For. Serv. Gen. Tech. Rep. PNW-4.

Chavez-Ramirez, F., and R.D. Slack. 1994. Effects of avian foraging and post-foraging behavior on seed dispersal patterns of ashe juniper. Oikos 71:40-46.

Clary, W.P. 1971. Effects of Utah juniper removal on herbage yields from springerville soils. J. Range Manage. 24:373-378.

Clary, W.P., M.B. Baker, P.F. O'Connell, T.U. Johnsen, and R.E. Campbell. 1974. Effects of pinyon-juniper removal on natural resources products and uses in Arizona. Res. Pap. RM-128, USDA For. Ser. Rocky Mtn. For. and Range Exp. Sta. Ft. Collins, CO. 28 pp.

Clary, W.P., and D.A. Jameson. 1981. Herbage production following tree and shrub removal in the pinyon-juniper type of Arizona. J. Range Manage. 34:109-113.

Clary, W.P., and D.C. Morrison. 1973. Large alligator juniper benefits early spring forage. J. Range Manage. 26:70-71.

Cole, D.N. 1990. Trampling disturbance and recovery of cryptogamic soil crusts in Grand Canyon National Park. Great Basin Nat. 50(4):321-325.

Cole, K. 1983. Late Pleistocene vegetation of Kings Canyon, Sierra Nevada, California. Quat. Re. 19:117-129.

Collings, M.R. 1966. Throughfall for summer thunderstorms in a juniper and pinyon woodland. U.S. Geol. Surv. Prof. Paper 485-B.

Collings, M.R., and R.M. Myrick. 1966. Effects of pinyon and juniper eradication on streamflow from Corduroy Creek basin, Arizona. U. S. Geol. Surv. Prof. Paper. 491-B.

Corbett, E.S., and R.P. Crouse. 1968. Rainfall interception by annual grasses and chaparral ... losses compared. USDA, For. Serv. Res. Pap. PSW-98.

Cottam, W.P., and G. Stewart. 1940. Plant succession as a result of grazing and of meadow desiccation by erosion since settlement in 1862. J. For. 38:613-625.

Courturier, D.A., and E.A. Ripley. 1973. Rainfall interception in mixed grass prairie. Can. J. Plant Sci. 53:659-663.

Cressman, L.S. 1981. The Sandal and the Cave. Oregon State University Press, Corvallis, OR.

Crisp, M.D. 1975. Long-term change in arid zone vegetation at Koonamore, South Australia. Ph.D. dissertation. Univ. of South Australia, Adelaide. 373 pp.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Sci. 33(1):43-64.

Davis, J.N., K.T. Harper, and J. Brotherson. 1993. The influence of chaining juniper-pinyon woodland on some basic watershed values. p. 35. Abstracts. Presented a the 46th Annual Meeting of the Soc. of Range Manage., Vol. 46, Albuquerque, NM.

Davis, O.D. 1982. Bits and pieces: the last 35,000 years in the Lahontan area. Soc. Amer. Acrh. SAA Pap. No. 2, p. 53-75.

De Laubenfels, D.J. 1953. The external morphology of coniferous leaves. Phytomorphology 3:1-17.

Dealy, J.E. 1971. Habitat Characteristics of the silver/lake mule deer range. USDA For. Ser. Pac. NW For. and Rng.. Exp. Sta. Res. Pap. RNW-125. 99 pp.

Dealy, J.E. 1990. *Juniperus occidentalis* Hook. Western juniper. pp. 109-115. **IN:** USDA Handbook 654 Vol. 1, Silvics of North America.

Dealy, J.E., J.M. Geist, and R.S. Driscoll. 1978a. Western juniper communities on the rangelands of the Pacific Northwest. Proc. First Int. Range Cong.:201-204.

Dealy, J., J.M. Geist, and R.S. Driscoll. 1978b. Communities of western juniper in the Intermountain Northwest. pp. 11-29. **IN:** Proc. Western Juniper Ecology and Management Workshop. Bend, OR. 1977. pp. 11-29. USDA For. Ser. Gen. Tech. Rpt. PNW-74.

Dealy, J.E., D.A. Leeckenby, and D.M. Concannon. 1981. Wildlife habitats in managed rangelands - The Great Basin of southeastern Oregon: Plant communities and their importance to wildlife. Gen. Tech. Rpt. PNW-120.

Doescher, P.S., L.E. Eddleman, and M.R. Vaitkus. 1987. Evaluation of soil nutrients, pH, and organic matter in rangelands dominated by western juniper. Northwest Sci. 61(2):97-102.

Doescher, P.S., R. Miller and A. Winward. 1985. Effects of moisture and temperature on germination of Idaho fescue. J. Range. Manage. 38:317-320.

Donovan, L.A., and J.R. Ehleringer. 1991. Ecophysiological differences among juvenile and reproductive plants of several woody species. Oecologia 86:549-597.

Donovan, L.A., and J.R. Ehleringer. 1992. Contrasting water-use patterns among size and life-history classes of a semi-arid shrub. Functional Eco. 6:482-488.

Donovan, L.A., J. Mausberg, and J.R. Ehleringer. 1993. Seedling size and survival for *Chrysothamnus nauseosus*. Great Basin Nat. 53:237-245.

Dorf, E. 1936. A late Tertiary flora from Southwestern Idaho. Paleontology, Carnegie Inst., Wash. Pub. 476, 272 pp.

Dortignac, E.J. 1960. Water yield from pinyon-juniper woodlands. **IN:** Water yield in relation to environment in the southwestern United States. Committee on Desert and Arid Zones Research. Amer. Assoc. of the Adv. of Sci. Southwestern and Rocky Mtn. Div. 74 pp.

Driscoll, R.S. 1962. Characteristics of some ecosystems in the juniper zone in central Oregon. J. Range Manage. 15:347.

Driscoll, R.S. 1964a. A relict area in central Oregon juniper zone. Ecol. 45:345-353.

Driscoll, R.S. 1964b. Vegetation-soil units in the central Oregon juniper zone. USDA, Pac. NW For. and Range Exp. Sta. US For. Ser. Res. Pap. PNW 19. 60 pp.

Dunne, J. 1989. Cryptogamic crusts in arid ecosystems. Rangelands 11:180-182.

Dyksterhuis, E.L. 1981. Soil survey of Grant County, Oregon, Central Part. USDA, Soil Conserv. Serv.

Earle, C.J., and H.C. Fritts. 1986. Reconstructing river flow in the Sacramento Basin since 1560. Rep. Calif. Dept. Resources, Agreement No. DWR B-55395. Lab. of Tree-ring Res., Univ. Ariz., Tucson.

Eckert, R.E. Jr. 1957. Vegetation-soil relationships in some *Artemisia* types in northern Harney and Lake Counties, Oregon. Ph.D. Thesis. Oreg. State Univ., Corvallis. 208 pp.

Eddleman, L.E. 1983. Some ecological attributes of western juniper. pp. 32-34. **IN:** Agric. Exp. Sta. Spec. Rpt. 682. 1983 Progress Report...Research in Ranger Management. Oregon State University, Corvallis, OR.

Eddleman, L.E. 1984. Ecological studies on western juniper in central Oregon. pp. 27-35. **IN:** Oregon State University Extension Service. Proceedings - Western juniper management short course. Oct. 15-16. Bend, OR.

Eddleman, L.E. 1986. Canopy interception of precipitation. pp. 33-38. **IN:** 1986 Final Report, Water Resources Res. Inst., Oregon State Univ.

Eddleman, L.E. 1987a. Establishment of western juniper in central Oregon. pp. 255-259. **IN:** Everett, R.L. (compiler). Proc--Pinyon Juniper Conference; 1986 Jan. 13-16; Reno, NV. Gen. Tech. Rpt. INT-215. USDA, For. Ser. Intermountain Res. Sta. Ogden, UT.

Eddleman, L.E. 1987b. Ecological studies on western juniper in central Oregon. pp. 27-35. **IN:** Agric. Exp. Sta. Spec. Rpt. 803. 1987 Progress Report...Research in Range Management. Oregon State University, Corvallis, OR.

Eddleman, L.E., and P.M. Miller. 1992. Potential Impacts of western Juniper on the hydrologic cycle. pp. 176-180. **IN:** Clary, W.P., E.D. McArthur; D. Bedunah, C.L. Wambolt (compilers). 1992. Proceedings—symposium on ecology and management of riparian shrub communities; USDA, For. Serv. Gen. Tech. Rpt. INT-289.

Elmore, W. 1984. Juniper manipulation and the implications on wildlife habitat. pp. 48-52. **IN:** Oregon State University Extension Service. Proceedings - Western juniper management short course. Oct. 15-16. Bend, OR.

Erhard, D.H. 1980. Plant communities and habitat types in the Lava Beds National Monument, California. M.S. Thesis, Oregon State University, Corvallis, OR.

Evans, R.A. 1984. Plant succession following western juniper control with picloram. pp. 93-96. **IN:** Oregon State University Extension Service. Proceedings - Western juniper management short course. Oct. 15-16. Bend, OR.

Evans, R.A., and J.R. Ehleringer. 1993. A break in the nitrogen cycle in aridlands? Evidence from soils. Oecologia 94:314-317.

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

Evans, R.A., and J.A. Young. 1987. Control, plant succession, and revegetation in western juniper woodlands. pp. 301-304. **IN:** Everett, R.L. (compiler). Proceedings Pinyon-Juniper Conference, US For. Serv. Gen. Tech. Rpt. INT-215.

Field, C., and Mooney, H.A. 1986. The photosynthesis-nitrogen relations in wild plants. In: T. J. Givnish (Ed.), On the economy of plant form and function. Cambridge Univ. Press, New York, NY. pp. 25-55.

Franklin, J.F., and C.T. Dyrness. 1973. Natural vegetation of Oregon and Washington. USDA Forest Service Gen. Tech Rpt. PNW-8. 417 pp.

Freeman, D.C., E.D. McArthur, K.T. Harper, and A.C. Blauer. 1981. Influence of environment on the floral sex ratio on monoecious plants. Evol. 35:194-197.

Fresquez, P.R. 1990. Fungi associated with soils collected beneath and between pinyon and juniper canopies in New Mexico. Great Basin Nat. 50(2):167-172.

Fresquez, P.R., and G.L. Dennis. 1990. Composition of fungal groups associated with phyoedaphic communities in the semiarid Southwest. Arid Soil Res. and Rehab. 4:19-32.

Fritts, H.C., and W. Xiangdig. 1986. A comparison between response-function analysis and other regression techniques. Tree-ring Bull. 46:31-46.

Gabrielson, I.N., and S.G. Jewett. 1970. Birds of the Pacific Northwest. Dover Publ.

Gaither, R.E., and J.C. Buckhouse. 1981. Hydrologic outputs from woodland, shrubland, and grassland ecosystems in relation to grazing management strategies: An annotated bibliography. Agr. Exp. Sta., Spec. Rpt. 640, Oregon State University, Corvallis, OR.

Gaither, R.E. 1981. Storm runoff characteristics of various plant communities within the Oregon range validation area. M.S. Thesis. Oregon. State Univ. Corvallis, OR. 153 pp.

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

Ghil, M., and R. Vautgard. 1991. Interdecadal oscillations and the warming trend in global temperature time series. Nature 350:324-327.

Gholz, H.L. 1980. Structure and productivity of *Juniperus occidentalis* in Central Oregon. Amer. Midl. Nat. 103:251-261.

Gifford, G.F. 1970. Some water movement patterns over and through pinyon-juniper litter. J. Range Manage. 23:356-366.

Gifford, G.F. 1973. Runoff and sediment yields from runoff plots on chained pinyon-juniper sites in Utah. J. Range Manage. 26:440-443.

Gifford, G.F. 1975. Approximate annual water budgets of two chained pinyon-juniper sites in Utah. J. Range Manage. 28:73-74.

Gifford, G.F. 1982. Impact of burning and grazing on soil water patterns in the pinyon-juniper type. J. Range Manage. 35:697-699.

Gifford, G.F., and C.B. Shaw. 1973. Soil moisture patterns on two chained pinyon-juniper sites in Utah. J. Range Manage. 26:436-440.

Gifford, G.F., and R.K. Tew. 1969. Influence of pinyon-juniper conversions and water quality on permeability of surface soils. Water Resour. Res. 5:895-899.

Goodwin, J.R. 1993. Ecotypic variation, adaptation, and persistence of Idaho fescue on degraded central Oregon rangelands. M.S. Thesis. Department of Rangeland Resources, Oregon State University. Corvallis, OR. pp 250.

Graumlich, L. 1985. Long-term records of temperature and precipitation in the Pacific Northwest derived from tree rings. PhD. Thesis, University of Washington, Seattle.

Grayson, D.K. 1993. The Desert's Past: A Natural Prehistory of the Great Basin. Smithsonian Instn. Press, Washington D.C.

Green, G.L. 1975. Soil survey of Trout Creek-Shaniko Area, Oregon. USDA, Soil Con. Ser., US Gov. Prin. Office. 1975-O-524-786.

Gregg, M.A. 1991. Use and selection of nesting habitat by sage grouse in Oregon. Oregon State Univ. Thesis, Corvallis, OR.

Griffiths, D. 1902. Forage conditions on the northern boarder of the Great Basin. USDA Bureau of Plant Industry Bull. No. 15.

Griffiths, D. 1903. Forage conditions and problems in eastern Washington, eastern Oregon, northeastern California and northwestern Nevada. USDA Bureau of plant Industry Bull. No. 38.

Grondin, A.E., and J.R. Johansen. 1993. Microbial spatial heterogeneity in microbiotic crusts in Colorado National Monument: I. Algae. Great Basin Nat. 53(1):24-30.

Hall, F.C. 1973. Plant communities of the Blue mountains in Eastern Oregon and Southeastern Washington. USDA For. Ser. Pac. NW Region R6 Area Guide 3-1. 62 pp.

Hall, F.C. 1978a. Western juniper in association with other tree species. pp. 31-36. **IN:** Martin, R.E., J.E. Dealy, and D.L. Caraher (eds). Proc. West. Juniper Ecol. and Mange. Workshop. Bend OR. 1977. USDA For. Ser. Gen. Tech. Rpt. RNW-74.

Hall, F.C. 1978b. Blue mountains in Eastern Oregon and Southeastern Washington. USDA For. Ser. Pac. NW Region R6 Area Guide 3-1. 62 pp.

Hall, F.C. 1978c. Western juniper association with other tree species. **IN:** Proc. West. Juniper Ecol. and Manage. Workshop. Bend, OR. 1977. pp. 31-36. USDA For. Serv. Gen. Tech. Rpt. PNW-74.

Hansen, C.G. 1956. An ecological survey of the vertebrate animals on Steen's Mountain, Harney county, Oregon.   Ph.D. Thesis. Oregon State Univ. Corvallis, OR. 200 pp.

Harper, K.T., and J.R. Marble. 1988. A role for nonvascular plants in management of arid and semiarid rangelands. pp. 135-169. **IN:** Tueller, P.T. (ed.). Application of plant sciences to rangeland management and inventory. Kluwer Academic Publishers, Boston.

Henriksson, E., and B. Simu. 1971. Nitrogen fixation by lichens. Oikos 22:119-121.

Hepting, G.H. 1971. Diseases of forest and shade trees of the United States. USDA Handbook 386.

Hitchcock, C.L., A. Cronquist, M. Ownby, and J.W. Thompson. 1969. Vascular plants of the Pacific Northwest. Part I: Vascular cryptogams, gymnosperms, and monocotyledons. University of Washington Press, Seattle, WA.

Holmes, R.L. R.K. Adams, and H.C. Fritts. 1986. Tree-ring chronologies of western North America: California, eastern Oregon and Northern Great Basin. Laboratory of Tree-Ring Research, University of Arizona, Chronology Series VI.

Hopkins, W.E. 1979. Plant associations of the Fremont National Forest. USDA For. Serv., PNW Region, R6-ECOL-79-004.

Houston, D.B. 1973. Wildfires in northern Yellowstone National Park. Ecology 54:1109-1117.

Howard, V.W. Jr., K.M. Cheap, R.H. Hier, T.G. Thompson, and J.A. Diams. 1987. Effects of cabling pinyon-juniper on mule deer and lagomorph use. Pages 552-557. **IN:** R. Everett (ed.). Proc. - Pinyon-Juniper Conf. USDA For. Ser. Gen Tech. Rep. INT-215.

Hull Jr., A.C. 1972. Rainfall and snowfall interception by big sagebrush. Abs. Papers. proc. Utah Acad. Sci. 49:64-65.

Ingram, D.C. 1936. Notes on trimming *Juniperus occidentalis*. Soc. Amer. For. Proc. 1936:444.

Isichei, A.O. 1990. The role of algae and cyanobacteria in arid lands: A review. Arid Soil Res. and Rehab. 4:1-17.

Jaramillo, A.E. 1980. Wound periderm formation in *Juniperus occidentalis* in response to *Arceuthobium campylopodium*. Can. J. Bot. 58:400-403.

Jensen, C. 1945. Range condition: A classification of the grassland-juniper type of central Oregon. USDA Soil Con Ser. Pacific Coast Region.

Jensen, S.E. 1983. A survey of soil for the USU Range Experimental Area in Tintic Valley, Utah. Unpublished report to the USU Range Science Department, Logan, Utah.

Jeppesen, D.J. 1978. Competitive moisture consumption by the western juniper (*Juniperus occidentalis*). pp. 83-90. **IN:** Martin, R.E., J.E. Dealy, and D.L. Caraher (eds). Proc. West. Juniper Ecol. and Mange. Workshop. Bend OR. 1977. USDA For. Ser. Gen. Tech. Rpt. RNW-74.

Johansen, J.R. 1993. Cryptogamic crusts of semiarid and arid lands of North America. J. of Phycology 28:139-147.

Johansen, J.R., and L.L. S. Clair. 1986. Cryptogamic soil crusts: Recovery from grazing near Camp Floyd State Park, Utah, USA. Great Basin Nat. 46(4):632-640.

Johansen, J.R., A. Javakul, and S.R. Rushforth. 1982. Effects of burning algae communities of a high desert soil near Wallsburg, Utah. J. Range Manage. 35:598-600.

Johnsen, T.N. 1962. One-seed juniper invasion of northern Arizona grasslands. Ecol. Monogr. 32:187-207.

Johnson, A.H., and G.A. Smathers. 1976. Fire history and ecology, Lava Beds National Monument. **IN:** Proc. 15th Tall Timbers Fire Ecol. Conf. Tall Timbers Res. Stn. Tallahasse, Fla. 103 pp.

Johnson, C.G. Jr., and R.R. Clausnitzer. 1992. Plant associations of the Blue and Ochoco mountains. USDA, For. Serv. R6-ERW-TP-036-92.

Johnson, C.G. Jr., and S.A. Simon. 1987. Plant associations of the Wallowa-Snake Province, Wallowa-Whitman National Forest. USDA For. Serv., PNW Region Rep. R6-ECOL-TP-225B-86. Portland, OR.

Johnson, H.B., S.S. Mayeux, Jr., and H.W. Polley. 1990. Increasing atmospheric CO_2 concentrations and vegetation change on rangelands. Proc. Soc. Range Manage. 43rd Annual Meeting. Reno, Nevada.

Josaitis, R.M. 1991. The effects of western juniper occupancy on changes in soil characteristics in relation to shrub and grass establishment in Owyhee County, Idaho. Thesis. University of Idaho. 109 pp.

Kauffman, J.B., and D.B. Sapsis. 1989. The natural role of fire in Oregon's high desert. pp. 15-19. **IN:** Oregon's High Desert: The Last 100 Years. Spec. Rep. 841., Agr. Exp. Stn., Oregon State Univ., Corvallis, OR.

Keen, F.P. 1937. Climatic cycles in eastern Oregon as indicated by tree rings. Monthly Weather Rev. 65(5):175-188.

Keen, F.P. 1952. Insect enemies of the western forests. USDA Miscellaneous Pub. 273.

Kindschy, R.R., C. Sunderstrom, and J.D. Yoakum. 1982. Wildlife habitat in managed rangelands - the Great Basin of southeastern Oregon: pronghorns. USDA For. Ser. Gen. Tech. Rep. PNW-145.

Klein, W.M. 1958. Cotyledon variations in *Juniperus occidentalis* Hook. El Aliso. 4(1):129.

Kleiner, E.F., and K.T. Harper. 1977. Soil properties in relation to cryptogamic groundcover in Canyonlands National Park. J. Range Manage. 30(3):202-205.

Klopatek, C.C., L.F. DeBano, and J.M. Klopatek. 1988. Impact of fire on the microbial processes in pinyon-juniper woodlands: Management implications. pp. 197-205. **IN:** Effects of Fire Management of Southwestern Natural Resources, Proc. Symp. Tucson, AZ: USDA For. Serv. Gen. Tech. Rpt. RM-191.

Klopatek, J.M. 1991. The use of cryptogamic crusts as indicators of disturbance in semiarid landscapes. Ecol. Indicators. Springer-Verlag, NY.

Kramer, S. 1990. Development and morphology of juvenile western juniper (*Juniperus occidentalis* Hook.). M.S. Thesis. Oregon State University, Corvallis, OR.

Kropf, J., R. Kastor, A. Isley, E. McKinney, and J. Cornwell. 1984. Mechanical control of western juniper. **IN:** Proc. Western Juniper Management Shortcourse. Oct. 15-16, Bend, OR.

Krueger, W.C., T.R. Bunch, and K. Killingsworth. 1979. Herbicides for control of western juniper. pp. 3-39. **IN:** 1979 Prog. Rpt. Res. in Rangeland Management. Spec. Rpt. 549. 39 pp. Agric. Exp. Sta. Corvallis, OR.

Kundaeli, J.N., and H.G. Reynolds. 1972. Desert cottontail use of natural and modified pinyon-juniper woodland. J. Range Manage. 25(2):116-118.

Ladyman, J.A.R., E. Muldavin, and R. Fletcher. 1993. Pattern and relationships of terrestrial cryptogam cover in two pinyon-juniper communities in New Mexico. pp. 97-104. **IN:** Proc. Managing Pinyon-Juniper Ecosystems for Sustainability and Social Needs. Santa Fe, NM. USDA For. Serv. Rocky Mtn. For. and Range Exp. Stn. Gen. Tech. Rpt. RM-236.

Larsen, R.E. 1993. Interception and water holding capacity of western juniper. Ph.D. Dissertation. Oregon State University, Corvallis, OR.

Leckenby, D.A. 1968. Influences of plant communities on wintering mule deer. Oreg. Game Comm. Res. Rpt. P.R. Proj. W-53-R.

Leckenby, D.A. 1978. Western juniper management for mule deer. pp. 137-161. **IN:** Martin, R.E., J.E. Dealy, and D.L. Caraher (eds). Proc. West. Juniper Ecol. and Mange. Workshop. Bend OR. 1977. USDA For. Ser. Gen. Tech. Rpt. RNW-74.

Leckenby, D.A. 1986. Keynote Address: Management of western juniper plant communities for cover and forage habitats of mule deer in eastern Oregon. pp. 3-10. **IN:** Fisser, H.G. (ed.), Proc. Wyoming Shrublands, 15th Wyoming Shrub Ecology Workshop., Dep. of Range Manage., Univ. of Wyoming.

Leckenby, D.A., and A.W. Adams. 1986. A weather severity index on a mule deer winter range. J. Range Manage. 39:244-248.

Leckenby, D.A., A.W. Adams, and R.W. Roberts. 1971. Mule deer winter range ecology and management. Oreg. State Game Comm. P-R Proj. Rep. W-70-R-1. 18 pp.

Leckenby, D.A. et al. 1982. Wildlife habitats in managed rangelands - the Great Basin of southeastern Oregon: mule deer. USDA For. Ser. Gen Tech. Rep. PNW-139.

Leckenby, D.A., and D.E. Toweill. 1983. Response of forage species seeded for mule deer in western juniper types of south-central Oregon. J. Range Manage. 36:98-103.

Lederer, R.J. 1977. Winter territoriality and foraging behavior of the Townsend's Solitaire. Am. Midl. Nat. 97:101-109.

Lent, S. 1984. Developing prescriptions for burning western juniper slash. pp. 77-90. **IN:** Oregon State University Extension Service. Proceedings - Western juniper management short course. Oct. 15-16. Bend, OR.

Lentz, R.D., and G.H. Simonson. 1986. A detailed soils inventory and associated vegetation of Northern Great Basin Experimental Station. Spec. Rpt. 760. Agr. Exp. Sta., Oregon State Univ., Corvallis. 184 pp.

Link, S.O., G.W. Gee, and J.L. Downs. 1990. The effect of water stress on phenological and ecophysiological characteristics of cheatgrass and Sandberg's bluegrass. J. Range Mange. 43:506-513.

Loope, W.L., and G.F. Gifford. 1972. Influence of a soil microfloral crust on selected properties of soils under pinyon-juniper in southeastern Utah. J. Soil and Water Conserv. 27:164-167.

MacGregor, A.H., and D.E. Johnson. 1971. Capacity of desert algal crusts to fix atmospheric nitrogen. Soil Sci. Soc. of Amer. Proc. 35:843-844.

Martin, R.E. 1978. Fire manipulation and effects in western juniper (*Juniperus occidentalis*) Hook. pp. 121-136. **IN:** Proc. West. Juniper Ecol. and Manage. Workshop. Bend, OR. 1977. USDA For. Ser. Gen. Tech Rpt. PNW-74.

Martin, R.E., and A.H. Johnson. 1979. Fire management of Lava Beds National Monument. pp. 1209-1217. **IN:** Linn, R.M. (ed.). Proc. of the First Conference of Science and Research in the National Parks. USDI Nat. Park Serv., Transactions Proc. Serial No. 5.

Martin, R.E., J. O`Dell, and T.C. Judl. 1977. Planning for prescribed burns in Eastern Oregon and Washington. USDA For. Ser. Gen. Tech. Rpt. PNW.

Maser, C., and J.S. Gashwiler. 1978. Interrelationships of wildlife and western juniper. pp. 37-82. **IN:** Proc. West. Jun. Ecol. and Mgmt. Workshop. USDA For. Ser. Gen. Tech. Rpt. PNW-74.

Maser, C., J.W. Thomas, and R.G. Anderson. 1984. Wildlife habitat in managed rangelands - the Great Basin of southeastern Oregon: the relationship of terrestrial vertebrates to plant communities. USDA For. Ser. Gen. Tech. Rep. PNW-172.

Mason, R.B. 1982. Response of birds and rodents to controlled burning in pinyon-juniper woodlands. M.S. Thesis. University of Nevada, Reno. 62 pp.

Mattison, J.L. 1978. Sediment potentials for selected ecological land units in central Oregon. M.S. Thesis. Oregon State Univ. Corvallis, OR. 147 pp.

Mayko, R.W., and G.K. Smith. 1960. Soil survey of the Prineville area, Oregon. USDA, Soil Conserv Serv. series 1955, No. 12.

McKinney, E. 1984. Western juniper control: From site selection to follow-up management. pp. 74-75. **IN:** Oregon State University Extension Service. Proceedings -Western juniper management short course. Oct. 15-16. Bend, OR.

McMillan, W.D., and R.H. Burgy. 1960. Interception loss from grass. J. Geophys. Res. 65:2389-2394.

Meeuwig, R.O., and R.B. Murray. 1978. Current research on pinyon-juniper in the Great Basin. pp. 97-103. **IN:** Martin, R.E., J.E. Dealy, and D.L. Caraher (eds). Proc. West. Juniper Ecol. and Mange. Workshop. Bend OR. 1977. USDA For. Ser. Gen. Tech. Rpt. RNW-74.

Mehringer, P.J. Jr. 1987. Late Holocene environments on the northern periphery of the Great Basin. Final Rpt. Bureau of Land Management, Oregon State Office. Contract YA551-CT5-340075

Mehringer, P.J., and P.E. Wigand. 1984. Prehistoric distribution of western juniper. pp. 1-9. **IN:** Oregon State University Extension Service. Proceedings - Western juniper management short course. Oct. 15-16. Bend, OR.

Mehringer, P.J. Jr., and P.E. Wigand. 1987. Western juniper in the Holocene. pp. 109-119. **IN:** Everett, R.L. (ed.). Proc. Pinyon Juniper Conference, Gen. Tech. Rep. INT-215, USDA, For. Serv. Intermountain For. and Range Exp. Stn., Ogden, UT.

Mehringer, P.J. Jr., and P.E. Wigand. 1990. Comparison of late Holocene environments from woodrat middens and pollen: Diamond Craters, Oregon. pp. 294-325. **IN:** Betancourt, J.L., T.R. Can Devender, and P.S. Martin (eds.). Packrat Middens: The Last 40,000 Years of Biotic Change. Univ. of Arizona Press, Tucson, AZ.

Mettig, B. 1991. Biological surface features of semiarid lands and desert. pp. 257-293. **IN:** Skujins, J. (ed.). Semiarid lands and deserts: soil resource and reclamation. Marcel Dekker, Inc. New York.

Miller, P.M. 1990. Physiological ecology of western juniper (*Juniperus occidentalis* Hook. ssp. *occidentalis*). Ph.D. Dissertation. Oregon State University, Corvallis, OR.

Miller, P.M., L.E. Eddleman, and S. Kramer. 1990. Allocation patterns of carbon and minerals in juvenile and small-adult *Juniperus occidentalis*. For. Sci. 36:734-747.

Miller, P.M., L.E. Eddleman, and J.M. Miller. 1991a. The response of juvenile and small-adult western juniper (*Juniperus occidentalis*) to reductions in above and belowground tissue. Can. J. For. Res. 21:207-216.

Miller, P.M., L.E. Eddleman, and J.M. Miller 1991b. The response of western juniper (*Juniperus occidentalis*) to reductions in above- and below-ground tissue. Can. J. For. Res. 21: 207-216.

Miller, P.M., L.E. Eddleman, and J.M. Miller. 1991c. The response of juvenile and small-adult western juniper (*Juniperus occidentalis*) to nitrate and ammonium fertilization. Can. J. Bot. 69:2344-2352.

Miller, P.M., L.E. Eddleman, and J.M. Miller. 1992. The seasonal course of physiological processes in *Juniperus occidentalis*. For. Ecol. and Manage. 48:185-215.

Miller, P.M., L.E. Eddleman, and J.M. Miller. 1993. Influence of vapor pressure deficit and soil moisture on gas exchange of *Juniperus occidentalis*. NW Sci. 67:147-155

Miller, P.M., L.E. Eddleman, and J.M. Miller. in press. Advantages and disadvantages of juvenile foliage for a stress tolerant, invasive conifer. Can. J. For. Res.

Miller, R.F. 1984. Water use by western juniper. pp. 3-5. **IN:** Agric. Exp. Sta. Spec. Rpt. 715. 1984 Progress Report...Research in Range Management. Oregon State University, Corvallis, OR.

Miller, R.F. 1988. Comparison of water use by *Artemisia tridentata* spp.*wyomingensis* and *Chrysothamnus viscidiflorus* spp. *viscidiflorus*. J. Range. Mange. 41:58-62.

Miller, R.F., R.F. Angell, and L.E. Eddleman. 1987. Water use by western juniper. pp. 418-422. **IN:** Everett, R.L. (compiler). Proc--Pinyon Juniper Conference; 1986 Jan. 13-16; Reno, NV. Gen. Tech. Rpt. INT-215. USDA, For. Ser. Intermountain Res. Sta. Ogden, UT.

Miller, R.F., L.E. Eddleman, and R.F. Angell. 1986. Effects of juniper woodlands on upland hydrologic cycles. pp. 31-34. **IN:** Fisser, H.G. (ed.), Proc. Wyoming Shrublands, 15th Wyoming Shub Ecology Workshop., Dep. of Range Manage., Univ. of Wyoming.

Miller, R.F., L.E. Eddleman, and R.F. Angell. 1987. Relationship of western juniper stem conducting tissue and basal circumference to leaf area and biomass. Great Basin Nat. 47:349-354.

Miller, R.F., and J.A. Rose. 1995. Western juniper expansion in eastern Oregon. Great Basin Nat.

Miller, R.F., and L.M. Schultz. 1987. Water relations and leaf morphology of *Juniperus occidentalis* in the northern Great Basin. For. Sci. 33:690-706.

Miller, R.F., and P.E. Wigand. 1994. Holocene changes in semiarid pinyon-juniper woodlands. Bio. Sci. 44:465-474.

Nasri, M., and P.S. Doescher. in press. a. Effect of temperature on growth of cheatgrass and idaho fescue. J. Range. Manage.

Nasri, M., and P.S. Doescher. in press. b. Effect of competition by cheatgrass on shoot growth of Idaho fescue. J. Range. Manage.

Ndawula-Senyimba, M.S., V.C. Brink, and A. McLean. 1971. Moisture interception as a factor in the competitive ability of bluebunch wheatgrass. J. Range Manage. 24:198-200.

Neilson, R.P. 1987. On the interface between current ecological studies and the paleobotany of pinyon-juniper woodlands. pp. 93-98. **IN:** Everett, R. (ed.). Proc. - Pinyon-juniper Conference. USDA For. Serv., Gen. Tech. Rep. INT-215.

NOAA. 1982. Monthly normals of temperature, precipitation, and heating and cooling degree days 1951-1980 Oregon. No. 81. National Climate Center, Washington, DC. pp 73.

Nobel, P.S. 1983. Biophysical plant physiology and ecology. W. H. Freeman and Co. San Francisco, CA. pp. 608.

Nowak, C.L., R.S. Nowak, R.J. Tausch, and P.E. Wigand. 1994. Tree and shrub dynamics in northwestern Great Basin woodland and shrub steppe during the late-Pleistocene and Holocene. Amer. J. Bot. 81:265-277.

O'Meara, T.E., J.B. Haufler, L.H. Stelter, and J.G. Nagy. 1981. Nongame wildlife responses to chaining of pinyon-juniper woodlands. J. Wildl. Manage. 45(2):381-389.

Oswald, D.D. 1990. The juniper resources of eastern Oregon. Completion Rpt. USDI, Bureau of Land Management. PNW-87-527.

Paul, E.A., and F.E. Clark. 1989. Soil Microbiology and Biochemistry. Academic Press. New York.

Peek, M.E. 1925. A preliminary sketch of the plant regions of Oregon II. The Cascade Mountains and eastward.

Penning De Vries, F.W.T., A.H.M. Brunstring, and H.H. van Larr. 1974. Products, requirements and efficiency of biosynthesis: a quantative approach. J. Theor. Bio. 45:339-377.

Peter, D.H. 1977. Analysis of tree rings of *Juniperus occidentalis* from southeastern oregon. M. S. Thesis. Washington State University, Pullman, WA. 89 pp.

Petrini, O., and G. Carroll. 1981. Endophytic fungi in the foliage of some *Cupressaceae* in Oregon. Can. J. Bot. 59:629-636.

Podder, S., and R.J. Lederer. 1982. Juniper berries as an exclusive winter forage for Townsend's solitaires. Amer. Midl. Nat. 108:34-40.

Polley, H.W., H.R. Johnson, B.D. Marino, and H.S. Mayeux. 1993. Increase in C3 plant water-use efficiency and biomass over glacial to present CO_2 concentrations. Nature 361:61-64.

Pomerening, J.A., L. Thomas, and B. Thomas. 1983. Interim soil survey report of the Brothers area, Privevillle, Oregon district. USDA, Bureau of Land Manage. and USDA, Soil Conserv. Serv.

Puchy, C.A, and D.B. Marshall. 1993. Oregon wildlife diversity plan. Oregon Dept. of Fish and Wildlife, Portland, Oregon.

Quinsey, S.D. 1984. Fire and grazing effects in western juniper woodlands of central Oregon. M.S. Thesis. University of Wash. Seattle, WA.

Ramsey, K.J. 1989. Influence of leachates from western juniper slash on three native grasses. M.S. Thesis, Oregon State University, Corvallis, OR.

Reddy, G.B., and J. Gibbons. 1975. Nitrogen fixation by algae on fescue-grass soil crusts. Soil Sci. Soc. Amer. 39:654-656.

Renard, K.G., E.D. Shirley, J.R. Williams, and A.D. Nicks. 1987. Hydrology component: Upland phases. pp. 17-30 In SPUR: Simulation of production and utilization of rangelands. Documentation and user guide. J. R. Wright and J. W. Skiles (eds.). USDA Agric. Res. Serv., Beltsville, MD. ARS 63.

Rich, E.E., A.M. Johnson, and B.R. Baker (eds.). 1950. Peter Skene Ogden's Snake Country Journals: 1824-25 and 1825-26. The Hudson Bay Society, London.

Rose, J.A., and L.E. Eddleman. 1987. Ponderosa pine (*Pinus ponderosa* Dougl.) and understory response to western juniper (*Juniperus occidentalis*) removal. pp. 50-51. **IN:** Ponderosa pine: The Species and Its Management. A Symposium. Spokane, WA.

Rose, J.A. 1989. The effect of western juniper removal on ponderosa pine and associated understory vegetation. M.S. Thesis. Oregon State Univ., Corvallis.

Rose, J., and L. Eddleman. 1986. Ponderosa pine and understory vegetation response to western juniper removal. pp 19-21. **IN:** Agric. Exp. Sta. Spec. Rpt. 773. 1986 Progress Report...Research in Ranger Management. Oregon State University, Corvallis, OR.

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

Rychert, R.C., and J. Skujins. 1974. Nitrogen fixation by blue-green algae-lichen crusts in the Great Basin desert. Soil Sci. Soc. of Amer. Proc. 38:768-771.

Schlatterer, E.F., and E.W. Tisdale. 1969. Effects of litter of *Artemisia, Chrysothamnus*, and *Tortula* on germination and growth of three perennial grasses. Ecology 50(5):869-873.

Scholl, D.G. 1971. Soil wettability in Utah juniper stands. Soil Sci. Soc. Amer. Proc. 35:344-345.

Sedgewick, J.A. 1987. Avian habitat relationships in pinyon-juniper woodland. Wilson Bull. 99:413-431.

Sedgwick, J.A., and R.A. Ryder. 1987. Effects of chaining pinyon-juniper on nongame wildlife. Pages 541-551. **IN:** R. Everett (ed.). Proc. - Pinyon-Juniper Conf. USDA For. Ser. Gen. Tech. Rep. INT-215.

Severson, K.E. 1984. Rodent response to pinyon-juniper control — 13 to 18 years post-treatment. Abs. Soc. Range Manage. Annual Meeting. 37:25.

Severson, K.E. 1986. Small mammals in modified pinyon-juniper woodlands, New Mexico. J. Range Manage. 39(1):31-34.

Sheehy, D. 1978. Characteristics of shrubland habitat associated with mule deer fawns at birth and during early life in southeastern Oregon. Oregon Dept. Fish and Wildl. Corvallis, OR.

Shields, L.M., C. Mitchell, and F. Drouet. 1957. Algae and lichen stabilized surface crusts as soil nitrogen sources. Amer. J. of Bot. 44:489-498.

Shinn, D.A. 1978. Man and the land: An ecological history of fire and grazing in eastern Oregon rangeland. M.S. Thesis. Oreg. State Univ., Corvallis, OR.

Shinn, D.A. 1980. Historical perspective on range burning in the inland pacific Northwest. J. Range Manage. 33:415-422.

Skau, C.M. 1964a. Soil moisture storage under natural and cleared stands of alligator and Utah juniper in northern Arizona. USDA For. Serv. Res. Note RM-24.

Skau, C.M. 1964b. Interception, throughfall and stemflow in Utah and alligator juniper cover types of northern Arizona. For. Sci. 10:283-287.

Smeins, F.E., M.K. Owens, and S.D. Fuhlendorf. 1994. Biology and ecology of ashe (blueberry) juniper. pp. 9-24. **IN:** Taylor C.A. Jr. (compiler). 1994 Juniper Symp. Proc. Tech. Rpt. 94-2. Texas A&M Res. Sta. Sanora, TX.

Snyder, J.M., and L.H. Wullstein. 1973. The role of desert cryptogams in nitrogen fixation. Amer. Natur. 90:257-265.

Solomanson, M.G., and R.P. Balda. 1977. Winter territoriality of Townsend's solitaire (*Myadestes townsendi*) in a pinyon-juniper-ponderosa pine ecotone. The Condor 79:148-161.

Sowder, J.E., and E.L. Mowat. 1958. Silvical characteristics of western juniper. USDA For. Ser. Pac. NW For. and Rng. Exp. Sta. Silvical Series 12.

St. Clair, L.L., and J.R. Johnsen. 1993. Introduction to the symposium on soil crust communities. Great Basin Natur. 53(1):1-3.

Sudsworth, G.B. 1915. The cypress and juniper trees of the Rocky Mountain region. USDA Bull. N. 207. 36 pp.

Tausch, R.J. 1980. Allometric analysis of plant growth in woodland communities. Ph.D. Dissertation. Utah State Univ., Logan, UT.

Thompson, D. 1916. David Thompson's narrative. J.B. Tyrrel (ed.). The Champlain Society, Toronto, Ontario, Can.

Thompson, R.S., L. Benson, and E.M. Hattori. 1986. A revised chronology for the last Pleistocene Lake cycle in the central Lahontan Basin. Quat. Res. 25:1-10.

Thompson, R.S. 1990. Late Quaternary vegetation and climate in the Great Basin. pp. 200-239. **IN:** J.L. Betancourt, T.R. Van Devender, and P.S. Martin (eds.). Packrat Middens: The last 40,000 years of biotic change. University of Arizona Press, Tucson.

Tiedemann, A.R. 1987. Nutrient accumulations in pinyon-juniper ecosystems - managing for future productivity. pp. 352-359. **IN:** Everett, R.L. (ed.). Proc. Pinyon Juniper Conference, Gen. Tech. Rep. INT-215. USDA, For. Serv. Intermountain For. and Range Exp. Sta., Ogden, UT.

Tiedemann, A.R., and J.D. Klemmedson. In press. The influence of western juniper development on soil nutrient availability.

Tonsfeldt, W. 1984. Settling the central Oregon range—1860-1984. pp. 10-22. **IN:** Oregon State University Extension Service. Proceedings - Western juniper management short course. Oct. 15-16. Bend, OR.

Trainer, C.E., M.J. Willis, G.P. Keister, Jr., and D.P. Sheehy. 1983. Fawn mortality and habitat use among pronghorn during spring and summer in southeastern Oregon. Oregon Dept. Fish and Wildl. Res. Rep. No. 12. Portland, OR.

U.S. Department of Agriculture, Forest Service, PNW Experiment Station. 1936. Forest type maps — State of Oregon. Andrews, H.S., and R.W. Cowlins (preparers). NW, EW, NE, SE Quarters.

U.S. Department of Agriculture, Forest Service, PNW Experiment Station. 1936. The forest survey of eastern Oregon and eastern Washington. 8 pp.

U.S. Department of Agriculture, Forest Service. 1974. Seeds of woody plants in the United States. U.S. Dept. Agric. Handb. 450.

U.S. Department of Agriculture, Forest Service, Forest-Range Task Force. 1972. The nation's range resources - a forest range environmental study. USDA, For. Serv. Res. Rep. 19.

U.S. Department of Agriculture, Soil Conservation Service. Various dates. Technical Guide — Site Descriptions for Oregon.

USDI-BLM. 1990. The juniper resources of eastern Oregon. USDA, Bur. of Land Manage. Info. Bull. OR-90-166.

Vaitkus, M.R. 1986. Effects of western juniper on understory herbage production in central Oregon. M.S. Thesis. Oregon State University. Corvallis, OR.

Vaitkus, M.R., and L.E. Eddleman. 1985. Understory herbage response to western juniper (*Juniperus occidentalis*) removal in central Oregon. pp. 1-3. **IN:** Agric. Exp. Sta. Spec. Rpt. 743. 1985 Progress Report...Research in Rangeland Management. Oregon State University, Corvallis, OR.

Vaitkus, M.R., and L.E. Eddleman. 1987. Composition and productivity of a western juniper understory and its response to canopy removal. pp. 456-460. **IN:** Everett, R.L. (ed.). Proc. Pinyon Juniper Conference, Gen. Tech. Rep. INT-215. USDA, For. Serv. Intermountain For. and Range Exp. Sta., Ogden, UT.

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

Varughese, G.K., and C.L. Calvin. 1984. Growth of the endophytic system of *Phoradendron juniperinum* (Viscaceae) in shoots of *juniperus occidentalis*. Amer. J. Bot. 71:51.

Vasek, F.C. 1966. The distribution and taxonomy of three western junipers. Brittonia. 18:350-372.

Vasek, F.C., and R.F. Thorne. 1977. Transmontane coniferous vegetation. pp. 797-832. **IN:** M.G. Barbour, and J. Major (eds.). Terrestrial Vegetation of California. California Native Plant Society. Spec. Publ. No. 9.

Verts, B.J, S.D. Gehman, and K.J. Hundertmark. 1984. *Sylvilagus nuttallii*: a semiboreal lagomorph. J. Mamm. 65:131-135.

Volland, L.A. 1976. Plant communities of the Central Oregon pumice zone. USDA For. Serv., Area Guide 4-2.

Volland, L.A., and J.D. Dell. 1981. Fire effects on Pacific Northwest forest and range vegetation. USDA, For. Serv., R6-RM067.

von Rudloff, E., L. Hogge, and M. Granat. 1980. The leaf oil terpene composition of *Juniperus occidentalis*. Phytochem. 19:1701-1703.

Wells, P.V. 1983. Paleobiogeography of montane islands in the Great Basin since the last glaciopluvial. Ecol. Monogr. 53:341-382.

West, N.E. 1984. Factors affecting treatment success in the pinyon-juniper type. **IN:** Johnson, K.L. (ed.). Proc. 2nd Utah Shrub Ecol. Workshop. Utah State Univ., Logan.

West, N.E. 1988. Intermountain deserts, shrub steppes, and woodlands. pp. 209-230. **IN:** Barbour, M.B., and W.E. Billings (eds). *American Terrestrial Vegetation*. Cambridge Univ. Press, New York.

West, N.E. 1990. Structure and function of microphytic soil crusts in wild ecosystems of arid to semiarid regions. Adv. in Ecol. Res. 20:179-223.

West, N.E., K.H. Rea, and R.J. Tausch. 1975. Basic synecological relationships in juniper-pinyon woodlands. pp. 41-52. **IN:** The Pinyon-Juniper Ecosystem: a symposium. Utah Agric. Exp. Sta., Logan, UT.

Wexler, A. 1976. Vapor pressure formulation for water in the range 0° to 100°C. A revision. J. Res. Natl. Bur. Stand. (U. S.), 80A pp. 775-785.

Wexler, A. 1977. Vapor pressure formulation for ice. J. Res. Natl. Bur. Stand. (U.S.), 81A. pp. 5-20.

Wheeler, C.C., V.R. Flechtner, and J.R. Johansen. 1993. Microbial spatial heterogeneity in microbiotic crusts in Colorado National Monument: II. Bacteria. Great Basin Natur. 53:31-39.

Wigand, P.E. 1987. Diamond Pond, Harney County, Oregon: Vegetation history and water table in the eastern Oregon desert. Great Basin Nat. 47:427-458.

Wigand, P.E., and C.L. Nowak. 1992. Dynamics of northwest Nevada plant communities during the last 30,000 years. pp. 40-62. **IN:** C.A. Hall, V. Doyle-Jones, and B. Widawski (eds.). The History of Water: Eastern Sierra Nevada, Owens Valley, White-Inyo Mountains. White Mountain Research Station Symposium Volume 4.

Wilcox, B.P. 1994. Runoff and erosion in intercanopy zones of pinyon-juniper woodlands. J. Range Manage. 47:285-295.

Wilcox, B.P., K.M. Wood, and I.M. Tromble. 1988. Factors influencing infiltrability of semiarid mountain slopes. J. Range Manage. 41:197.

Williams, G., G.F. Gifford, and G.B. Coltharp. 1972. Infiltrometer studies on treated versus untreated pinyon-juniper sites in central Utah. J. Range Manage. 22:110-114.

Williams, K, F. Percival, J. Merino, and H.A. Mooney. 1987. Estimation of tissue construction cost from heat of combustion and organic nitrogen content. Plant, Cell, and Environ. 10:725-734.

Willis, M.J. et al. 1993. Sage grouse in Oregon. Oregon Dept. Fish Wildl. Res. Rep. No. 15. Portland, OR.

Wilson, L., M.E. Olsen, T.B. Hutchings, A.R. Southard, and A.J. Erikson. 1975. Soils of Utah. Agr. Exp. Sta. Bull. 492. Utah State Univ., Logan, UT. 94 pp.

Winegar, H., and W. Elmore. 1978. Mechanical manipulation of western juniper--some methods and results. pp. 106-119. **IN:** Proc. West. Juniper Ecol. and Manage. Workshop. Bend, OR. USDA For. Serv. Gen. Tech. Rep. PNW-74.

Winward, A.H. 1970. Taxonomic and ecologic relationships of the big sagebrush complex in Utah. Ph.D. Diss. Univ. of Idaho, Moscow, Ida. pp. 80.

Wood, M.F. 1988. Rangeland vegetation - hydrologic interactions. #19. pp. 469-491. **IN:** Tueller, P. (ed.). Vegetation science applications for rangeland analysis and management. Kluwer Acad. Press.

Wood, M.K. 1991. Watershed management. Proc. Piñon Conference, Santa Fe, NM.

Wood, J.C., M.K. Wood, and J.M. Tromble. 1987. Important factors influencing water infiltration and sediment production on arid lands in New Mexico. J. Arid Envir. 12:111-118.

Wright, H.A., F.M. Churchill, and W.C. Stevens. 1976. Effect of prescribed burning on sediment, water yield, and water quality from dozed juniper lands in Texas. J. Range Manage. 29:294-298.

Wright, H.A., L.F. Neuenschwander, and C.M. Britton. 1979. The role and use of fire in sagebrush-grass and pinyon-juniper plant communities: A state of the art review. USDA, For. Serv. Gen. Tech. Rpt. INT-58.

Young, J.A. 1984. Ecological studies of western juniper in northeastern California. pp. 44-45. **IN:** Oregon State University Extension Service. Proceedings - Western juniper management short course. Oct. 15-16. Bend, OR.

Young, J.A., and R.A. Evans. 1981. Demography and fire history of a western juniper stand. J. Range Manage. 34:501-506

Young, J.A., and R.A. Evans. 1984. Stem flow on western juniper (*Juniperus occidentalis*) trees. Weed Sci. 32:320-327.

Young, J.A., R.A. Evans, J.D. Budy, and A. Torrell. 1982. Cost of controlling western juniper trees. J. Range Manage. 35:437-442.

Young, J.A., R.A. Evans, J.D. Budy, and D.E. Palmquist. 1988. Stratification of seeds of western and Utah juniper. For. Sci. 34:1059-1066.

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