Demography and Fire History of a Western Juniper Stand

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Abstract

The age, density, and fire history of western juniper *(Juniperus occidentalis* Hook.) trees growing on range sites of contrasting potentials were investigated. The 1,000-ha study area consisted of 65% big sagebrush [*Artemisia tridentata* Nutt. subsp. *wyomingensis* (Rybd.) Beetle] and 30% low sagebrush (*A. arbuscula* Nutt.) plant communities. Density of western juniper trees was 150 and 28 trees/ha on the big and low sagebrush sites, respectively. The oldest western juniper found growing in the big sagebrush communities became established in 1855, and 84% of the existing trees became established between 1890 and 1920. The oldest trees on the low sagebrush sites had established by 1600, and most of the existing trees established before 1800. At the beginning of the 20th century, the western juniper populations on big sagebrush sites were doubling in density every 3 years. The rate of establishment on these sites has slowed until 1,370 years would now be required to double the population size. The rate of population growth on low sagebrush sites has varied from decade to decade with a trend to double the population every 200 years and trees that become senescent at about 400 years of age. About 0.4% of western juniper on the low sagebrush sites had fire scars, some of which indicated the occurrence of multiple fires. These fire scars indicated that since 1600 there were periods of up to 90 years when no fires scarred the trees. Changes in the frequency of wildfires appear to be the most logical explanation for the sudden invasion of trees into big sagebrush communities, but current technologies for reconstructing fire chronologies are woefully inadequate in this environment.

During the last century there has been a pronounced change in the distribution, density, and age structure of virtually all juniper woodlands in the western United States. For the southwestern United States such changes have been related to the influences of grazing animals and fire suppression (Johnson 1962, Arnold et al. 1964).

Western juniper (*Juniperus occidentalis* Hook.) woodlands are a northwestern extension of the extensive woodlands of the central Great Basin. There are two distinct subspecies of *J. Occidentalis: J. Occidentalis* Hook. subsp. *australis* Vasek, the Sierra juniper, which occurs from Lassen County, California, south through the Sierra Nevada mountains to the San Bernardino mountains of southern California; and *J. occidentalis Hook. subsp. occidentalis,* which occurs in northern California and adjacent Nevada, southwestern Idaho, and southeastern Washington, and reaches its greatest development in central Oregon east of the Cascade Mountains (Vasek 1966). The distribution of this subspecies generally follows that of the Columbia River Basalts (King 1959).

In the words of a land manager, "Where they grow, stands of western juniper are generally accepted as a characteristic part of the landscape. They appear to be well established and form a logical transition between the open plains and the pine timber. They look like they belong. A closer look raises some doubts." (Caraher 1978).

The doubts of many observers have been raised by the observation of even-aged stands with no senescent trees and no reproduction (Adams 1975). The soils of many of these stands appear to be adapted to support communities of big sagebrush (*Artemisia tridentata* Nutt.)/bluebunch wheatgrass [*Agropyron spicatum* (Pursh) Scribn. & Sm.]. At the same time there are stands of western juniper growing on relatively shallow or rocky soils or steep slopes, with all age classes represented, from seedling to senescent.

Our purpose in these studies was to take a distinct land form, stratify the plant communities according to potential, and determine the age, density, and fire history of the western juniper trees present.

Methods

The study area was located in western Lassen County, California. The site, known locally as Juniper Hill, consists of about 1,000 hectares (ha) of rangeland on a low hill that is clearly disjunct from the adjacent forested mountains. The western and northwestern sides of the hill confront cultivated fields of the Big Valley agricultural area. The southern base of the hill touches the alluvial soils of Willow Creek, which are farmed. The eastern flanks of Juniper Hill, which are its steepest portion, meet broad flats of low sagebrush (*Artemisia arbuscula* Nutt.). The valleys around Juniper Hill are about 1,350 m in elevation, and the summit of the hill is 1,430 m in elevation. The hill itself consists of a broken and tilted portion of a basalt flow, with the lowered portion toward the southeast and the raised portion toward the northwest.

Precipitation, occurring almost entirely during the winter and spring, is estimated at 30 cm, based on gauges located on the site and extrapolation from the nearest long-term weather station at Adin, California.

Juniper Hill has traditionally been used to winter cattle and to place cattle in the early spring, when the neighboring farmers begin to till their fields. The herbaceous vegetation and often the shrubs have been completely altered by this continued early grazing. The first settlement on Willow Creek began in the 1860's (Guinn 1906). Juniper Hill is subdivided into nine pastures of different ownership. A historical marker at the base of the hill on the Willow Creek side indicates that Providence School was located on the site in the 1870's to serve the children of homesteaders in the surrounding area.

Using aerial photographs and ground surveys, we mapped the plant communities of the entire hill in two broad categories: juniper/big sagebrush and juniper/low sagebrush. Under pristine conditions, there were probably several communities located on the hill, representing different potentials or habitat types (Driscoll 1964). A few remnant plants of bluebunch wheatgrass are apparent, but the herbaceous vegetation is now dominated by the alien annual grasses cheatgrass *(Bromus tectorum L.)* and medusahead [*Taeniatherum asperum* (Simonkai) Nevski]. It was not possible by working on Juniper Hill alone to reconstruct all pristine communities; therefore, only the broad classifications of big and low sagebrush were used.

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In a portion of the juniper/big sagebrush communities, we randomly established eight plots, each 0.1 ha in area. All trees growing in these plots were cut at the soil surface. The height, maximum crown diameter, trunk diameter above the swollen base, and number of growth rings were determined for each tree. We established 28 other 0.1-ha plots in juniper/big sagebrush communities on Juniper Hill. The same data were collected, except that the trees were not cut and the growth rings were not counted. The age of these trees was estimated with a regression equation based on height and diameter of the trunk. The equation was developed from the data obtained on the cut plots. In both the cut and uncut plots all trees were examined for evidence of fire scars.

In juniper/low sagebrush communities on the hill we established 32 additional 0.1-ha plots. The same data were collected as on plots in the juniper/big sagebrush communities. Fire scars were determined and interpreted by the methods of Arno and Sneck (1977). A separate regression equation was developed for estimating age of the western junipers on low sagebrush sites from tree height and trunk diameter. However, most of the trees on the low sagebrush sites were cut for age determination.

Results

Distribution of Plant Communities

About 66% of the 1,000-ha area of Juniper Hill is covered with western juniper/big sagebrush or big sagebrush-bitterbrush [*Purshia tridentata* (Pursh) DC.] plant communities (Table 1). Decaying stumps of old-growth trees that had been cut many years earlier were found on about 1% of the western juniper/big sagebrush area; no such stumps were found in the remaining portion of this community. Stumps were mainly found on steep, north-facing slopes below a ridge top, with only an occasional stump on top of the ridges (Fig. 1). Most of the old growth areas had low sagebrush communities located below them on the slopes. The remainder of the western juniper/big sagebrush occurred on gentle to slightly undulating slopes. The soils were shallow Typic Haploxerolls derived from basalt. These soils were a heavy clay loam, and soil depth ranged from 25 to 80 cm.

Table 1. Major effective environments on Juniper Hill study area.

Effective environment	Percent of total area
Western juniper/big sagebrush	59
Western juniper/low sagebrush	30
Western juniper/big sagebrush-bitterbrush	6
Rim rocks	4
Cut-over area	1

On aerial photographs, there were two distinct communities composed of open juniper woodlands with a bitterbrush-big sagebrush shrub layer (Fig. 1). The bitterbrush was still vigorous while in the remainder of the juniper/big sagebrush communities only dead bitterbrush plants were found. The density of juniper trees was lower than on the other big sagebrush sites. There were no soil or aspect differences to account for these differences. These areas may be old burns where the juniper population was reduced or eliminated and bitterbrush and juniper trees have reinvaded. We could find no fire records to indicate such a burn, and, despite a careful search, we found no fire scars on the existing juniper trees in these areas.

Dead stumps of bitterbrush plants were apparent throughout the remaining western juniper/big sagebrush woodlands. Historically, according to interviews with neighboring ranchers, Juniper Hill was noted for its excellent stands of bitterbrush. Early in the 20th century, children of neighboring ranchers had to hunt to find the dairy cows that were turned loose daily in the bitterbrush stands (Personal communication from Jerry Parks, Adin, California).

The western juniper/low sagebrush communities constitute 30% of the area and represent a contrasting environment. The soils of the low sagebrush areas are Duric Haplargids or Typic Durargids. The most striking thing about the soils of these low sagebrush communities is the biscuit and swale microtopography. In many of the swales, there is virtually no soil suitable for the growth of plants. The mounds or biscuits may have a soil depth of 10 to 20 cm. Soils in these low sagebrush communities are extremely wet in the spring after the snow melts and are baked hard in midsummer. Although they are contrasting environments, the low sagebrush and big sagebrush juniper woodlands form a mosaic in their physical distribution (Fig. 1).

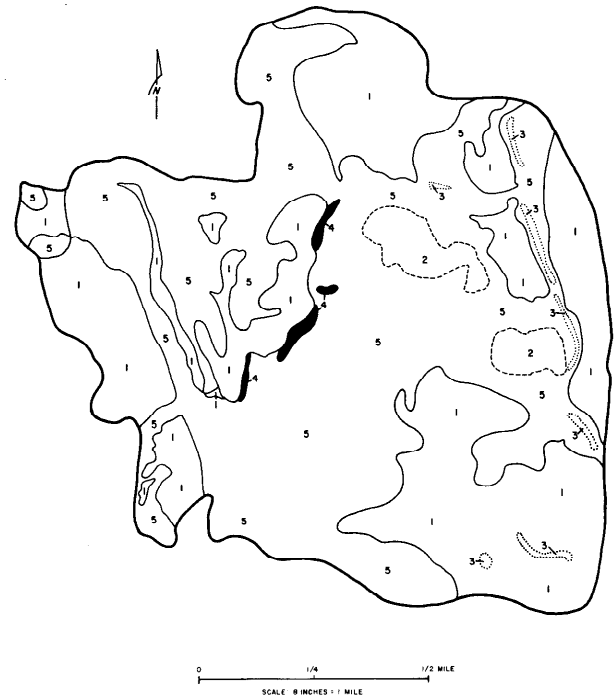

Fig. 1. *Distribution of major groups of plant communities on Juniper Hill study area: (1) western juniper/low sagebrush; (2) area of western juniper/big sagebrush-bitterbrush with a low density of trees; (3) rim rocks; (4) western juniper/big sagebrush with stumps from past utilization; and (5) western juniper/big sagebrush.*

The remaining community or effective environment on Juniper Hill consists of western junipers growing in cracks in basalt rim rocks. The community is not located on top of the rims, but occasional trees have become established and are growing on the near vertical faces of the rims and in the talus at the foot of the rock exposures.

Density of Western Juniper

The western juniper/big sagebrush woodlands are quite dense stands, averaging 150 trees/ha (Table 2). In contrast, the western juniper/low sagebrush communities have only 28 trees/ha, and the areas of relatively recent burns in big sagebrush-bitterbrush communities have only 25 trees/ha. Despite the density of trees in the big sagebrush communities the canopies are not closed. Projected cover of the juniper trees ranged from 40 to 60% in these communities. Although the crowns are not aerially closed, excavations for studies of the rooting habit of the trees have revealed that the interspaces between the trees are filled with tree roots, effectively

Table 2. Density (number per unit area) of western juniper trees in major plant communities on Juniper Hill study area.

Plant community	Density of western juniper trees (no./ha)
Western juniper/big sagebrush	150
Western juniper/low sagebrush	28
Western juniper/big sagebrush-bitterbrush	25

closing the stands (unpublished research, ARS, Reno, Nev.).

Periodicity of Establishments

Of the western juniper trees growing in big sagebrush communities, 84% established from 1890 to 1920 (Fig. 2). The oldest tree established in 1855, and only 6.4% established before 1890. Only 2.8% of the existing trees have established since 1930. We found no naturally dead juniper trees on the big sagebrush sites.

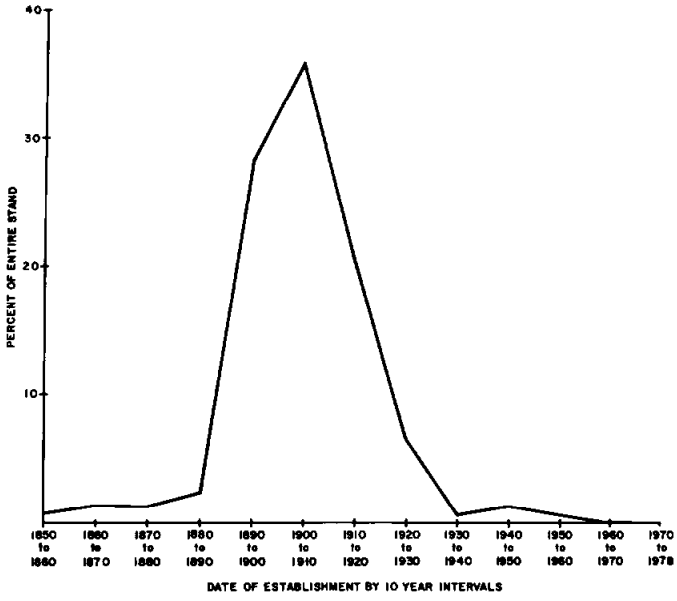

Fig. 2. *Periodicity of establishment of western juniper trees in big sagebrush communities on Juniper Hill, 1850-1978.*

The western juniper growing in the low sagebrush communities had a much greater mean age. The oldest trees, about 2% of the population, established by 1600 (Fig. 3). The centers of the apparently oldest trees were rotten, which prevented definite determinations of the establishment date, but it was no later than 1600. Most of the western juniper trees that were growing in low sagebrush communities established before 1800. From 1850 to 1900 there was a resurgence in establishment, which tapered off after 1900.

When interpreting the establishment curves for western juniper, it is important to keep in mind the relative density of the woodland on low and big sagebrush sites. Since 1900 on the low sagebrush sites 17% of the existing stands have become established, but this is roughly only five trees/ha. Since 1900 on the big sagebrush sites 98 trees have become established/ha.

By 1900, 83% of the current western juniper trees in the low sagebrush communities and 35% of those in the big sagebrush communities were established.

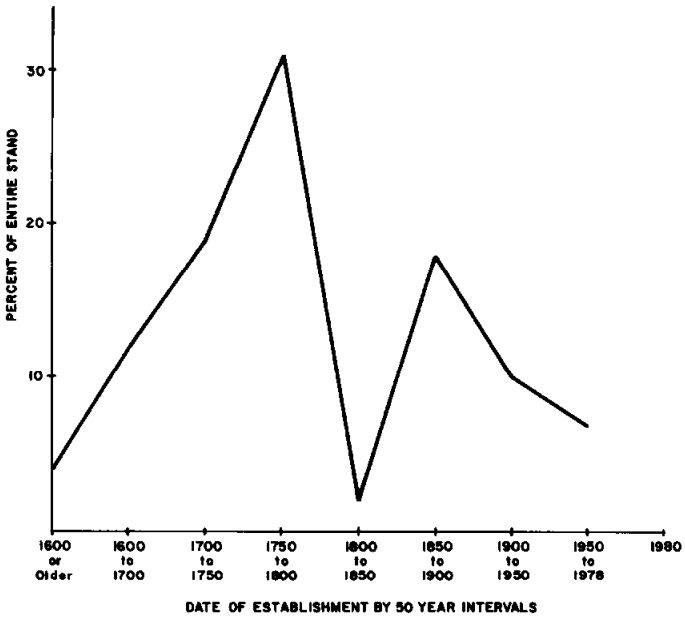

Fig. 3. *Periodicity of establishment of western juniper trees in low sagebrush communities on Juniper Hill, 1600-1978.*

Population Growth Rate

Using techniques suggested by Harper (1977) to express the growth rates of populations, we find that since 1910 the populations of western junipers growing on the low and big sagebrush sites have had virtually parallel growth curves (Fig. 4). There is, however, a 10-fold difference in tree density on the two sites.

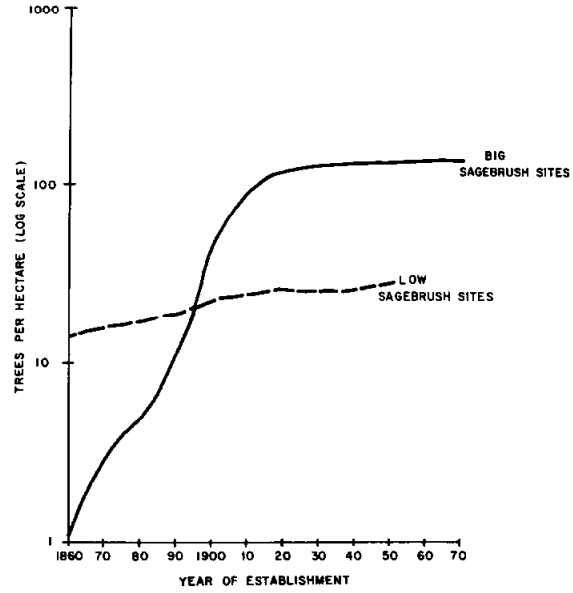

Fig. 4. *Population growth curves of western junipers on big and low sagebrush communities, based on survivors in 1978.*

The rate of population growth can be expressed as the number of years required to double population size (Harper 1977). When the western juniper populations were rapidly invading the big sagebrush sites at the turn of the century, the population size was doubling every 3 years (Table 3). At the same time the junipers growing on the low sagebrush sites required 48 years to double their population size. Since 1900 the population-size doubling rate has been relatively constant on the low sagebrush sites, except in the 1930's, when there was no growth. In contrast, on the big sagebrush sites, the time required for population doubling has consistently lengthened.

Possible Causes of Juniper Invasion

The three major hypotheses about why junipers have invaded shrub-grasslands attribute the invasion to: (a) grazing of domestic livestock, (b) suppression of wildfire, and (c) climatic shifts (Burkhardt and Tisdale 1969). Obviously the plant communities at Juniper Hill have been severely modified by years of intense grazing, but we do not have an ungrazed area to serve as a comparison,

Table 3. The time required for doubling of populations of western juniper growing on low and big sagebrush sites. The populations are those of survivors present in 1978.

	Time (years) to double population at indicated date							
Site	1870	1880	1890	1900	1910	1920	1930	1940
Big sagebrush	7	15	7	3	10	36	423	1370
Low sagebrush	70	160	53	48	230	240	—	250

so it is difficult to test this hypothesis experimentally. Likewise, the influence of climatic shifts is difficult to determine from our data base. At first glance it would appear possible to interpret the width of the annual growth rings on the western juniper trees as an index of climatic shifts, much in the manner of a dendrochronologist working with southwestern conifers (Douglas 1928). The major problems with applying these techniques are that the time span of the invasion is too short a period and the growth rate of a juniper tree in a dense stand reflects competition from neighboring trees as much or more than it does relatively brief climatic changes.

The remaining hypothesis about the sudden invasion of big sagebrush communities by western junipers attributes it to changes in the frequency or intensity of wildfires. Burkhardt and Tisdale (1969) made a very strong case for the influence of wildfires in limiting the spread of western junipers. Trees less than 50 years old are very susceptible to wildfires. Our sample of fire scars consisted of 28 trees from about 250 ha of woodland. There were three decades, 1640 to 1650, 1750 to 1760, and 1830 to 1840, when more than two trees were fire scarred (Fig. 5). Each one of these instances of wildfires probably represents one large fire. The variation in dates within the decade from which scars are identified is probably due to false or missing rings.

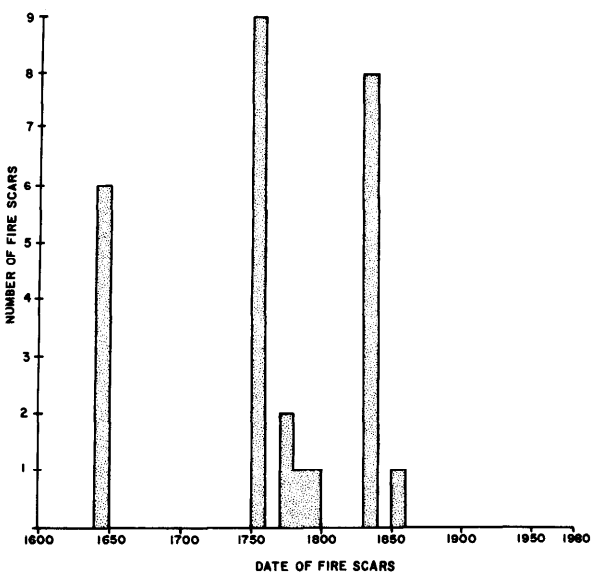

Fig. 5. *Frequency of fire scars on western juniper trees growing on low sagebrush sites.*

We found one remarkable tree that was doubly fire scarred by the fire of 1750 to 1760. The cambium was completely destroyed on opposite sides of the tree. Essentially the tree was divided into two separate trunks at the base. On these twin trunks were separate, but synchronous, fire scars for the decades of 1770, 1780, 1790, 1830, and 1850. The twin trunks differed by one annual growth ring for the century from 1878 to 1978 and by two rings for 1778 to 1878, and from the pith (1665) to 1878 they were identical. Although this tree was in a topoedaphic situation where it was susceptible to fire scarring in five successive fires, it grew from 1655 to 1750 without evidence of fire scarring. This type of evidence is hard to obtain, because successive fires often char through the center of the tree so that fire scars made early in the history of the tree are obliterated. In this case the separation of the trunks left the center of the trunk free of fire damage. If fire alone controlled the spread of western juniper, we suspect that this 100-year fire-free period would have allowed trees to extensively occupy the big sagebrush communities. If so, it seems probable that at least one tree in these areas would have survived.

The determining of fire histories from the occurrence of fire scars is an imprecise science. Not all fires scar all trees and not all trees are susceptible to scarring. As previously noted, juvenile western juniper trees are extremely susceptible to wildfires (Burkhardt and Tisdale 1969). The big sagebrush communities may have been burned by wildfires that failed to scar any of the trees growing on the low sagebrush sites.

Scarring of trees shows no evidence of promiscuous burning on Juniper Hill after settlement. The latest fire scar seen was dated in 1850 to 1860, the time of earliest settlements in this area. Low juniper populations, only 25/ha in two areas of big sagebrush bitterbrush, may be the result of recent burns, but there are no confirming fire scars.

The nine trees with fire scars dating to 1750 to 1760 and the eight trees with fire scars dating to 1830 to 1840 were located in diverse sections of Juniper Hill which indicates that these fires were common to the entire hill.

Old-Growth Tree

About 1% of Juniper Hill big sagebrush communities contained stumps of large western juniper trees. As previously noted, these sites were located on steep north-facing slopes, with low sagebrush flats located at the foot of the slopes. These sites were apparently relatively firesafe; i.e., wildfires burned there only under extreme conditions. However, these were not fireproof, because 85% of the stumps had two prominent fire scars. On the low sagebrush sites only 0.4% of the living trees were fire scarred. The stumps were rotten enough that we could not count annual growth rings to estimate the dates of these fires. From the location of scars on the stumps in comparison with those on living trees that we cut on low sagebrush sites, these stump scars appeared to represent the 1750 and 1830 fires.

We found four trees in this old-growth area that had grown from limbs left below the cut surface of the stump; the limbs gained apical dominance and grew into a vertical trunk. Counts of the rings on these new trunks indicated that their age was 95 to 100 years. This would place the time of cutting of these trees in the late 1870's and early 1880's. Marks on the stumps indicate that the trees were cut with aces, probably by homesteaders making posts.

Why did these trees establish on north-facing, firesafe sites, but not in other big sagebrush communities? The sites' potential for establishment does not appear to be a factor, since all big sagebrush sites were susceptible to juniper invasion after 1880. The sites' potential for fire spread was most likely a determining factor.

We did not observe any past cutting of western junipers growing on low sagebrush sites. However, the old-growth trees that we cut on low sagebrush sites for fire-scar dating were always infested with a brown cubical rot, rendering the trunk unsuitable for split posts (Herbst 1977).

Seed Sources and Dispersal

Burkhardt and Tisdale (1969) followed the dispersal of juniper seeds with radioisotope-labeled seeds. They found that the dispersal was primarily downslope as a result of gravity. This type of dispersal is very evident below rim rocks on Juniper Hill. However, on the broad south- to south-east-facing slopes there were no upslope, old-growth stands to provide a seed source. Analysis of the percentages of stand establishment by decades in relation to distance from the low sagebrush sites revealed no marked differences in date of establishment (Table 4).

Table 4. Percentage of stand establishment of western junipers per decade in plots located at various distances from low sagebrush sites.[1]

	Establishment in indicated site (% of total)					
Decade	1	2	3	4	5	6
1880-1890	2	1	3	2	2	3
1890-1900	28	30	30	26	31	30
1900-1910	36	29	34	38	36	36
1910-1920	20	21	18	22	19	22

[1]Plot 1 was located at the margin of low sagebrush site and plot 6 was the farthest away.

One possible mode of invasion of big sagebrush sites is that a few trees became established and then produced seeds for further invasion. This does not, however, appear to be the case for Juniper Hill. Junipers have polymorphic foliage, with juvenile spines and adult scales. Western junipers do not flower when in juvenile foliage, and the spiny juvenile foliage stage lasts from 5 to 25 years, with a mean of 17 years (unpublished research, ARS, Reno, Nevada). Trees less than 50 years old produce few seeds. We have shown that during the rapid-population-growth phase at the turn of the century, the western juniper populations on the big sagebrush sites were doubling every 3 years. The seed source for this increase must have come from the trees on low sagebrush communities.

Ranchers in the Juniper Hill area report concentrations of robins *(Turdus migratorius)* feeding on juniper berries in the fall. Evidence of bird distribution is found in fencerow populations. At the base of Juniper Hill, soils that originally supported big sagebrush communities are tilled and low sagebrush soils remain in pastures. Fences crossing big sagebrush sites have 1.7 western juniper trees per 10 linear meters of fence; fences crossing low sagebrush sites have 0.1 tree per 10 linear meters. The fencerow juniper population is 100 times as dense on the big sagebrush site as on low sagebrush sites. The population on the fencerows passing through big sagebrush potential sites is 3.8 times as dense as the average population on big sagebrush communities, even though the fences were built on section lines.

All ages of juniper, from seedlings to 80-year-old trees, were found along these fencerows. There appears to be no question that there are juniper seeds dispersed along these fencerows, some of which are 1 km from the closest juniper stand.

Apparently, the seed source for invasion of the big sagebrush-potential sites by western juniper has always come from trees adapted for growth on the contrasting low sagebrush environments. One of the tenets of modern silviculture has been that the plant material most inherently adapted to a given site is that found growing on the site. With western juniper, low sagebrush sites with contrasting environmental potential support trees that produce seeds capable of germinating and establishing on big sagebrush / grass communities.

Less than 1% of the western juniper trees that have established on big sagebrush sites on Juniper Hill currently bear fruit. If the stand is disturbed and trees are removed, some of the pistillate trees will produce abundant seeds. Speculation on stand tenure and development and the testing of hypotheses on causes of the sudden invasion of big sagebrush communities by western juniper are important if management is to prevent such invasions in the future. Of immediate concern to managers is the fate of the dense stands of trees that established at the turn of the century. The longevity of trees growing on adjacent low sagebrush stands indicates that the trees will occupy the site for the next 3 centuries before they succumb to diseases and insect infestations. Sudworth (1908) estimated the longevity of western juniper as ranging from 500 to 800 years. On Juniper Hill, trees approaching 400 years of age appear to be nearing senescence. The stands of western juniper growing on big sagebrush sites may be much more susceptible to insects and pathogens, because of their density, than their older counterparts growing on low sagebrush sites.

Because they have purged their understories of almost all herbaceous and shrub vegetation, the western juniper communities growing on big sagebrush sites are virtually fireproof, except under the most severe burning conditions (Bruner and Klebenow 1979). Herbage production of the herbaceous vegetation in the juniper stands on the big sagebrush sites averaged less than 50 kg/ha.

Once the native perennial grasses were grazed out of the low sagebrush sites, they were virtually fireproof (Young and Evans 1971) and often were used as natural firebreaks in wildfire suppression. Many land managers have commented on this fact while wondering at the occurrence of fire scars on old-growth juniper trees in these communties. Where medusahead has invaded juniper/low sagebrush woodlands, the sites become extremely fire hazardous.

We have observed western juniper seedlings establishing in fully stocked stands of intermediate wheatgrass [*Agropyron intermedium* (Host) Beauv. var. *intermedium*]. These observations support the findings of Burkhardt and Tisdale (1969) that establishment of western juniper is relatively independent of grass density. In the final analysis it is apparent that none of the popular hypotheses about the causes of juniper invasion of former shrub/grasslands are entirely satisfactory in explaining the sudden establishment of western juniper trees in big sagebrush communities on Juniper Hill. Juniper Hill is a relatively small, specific landform, and theoretical assumptions should fit broad areas more precisely than specific land units. However, practical land management is most often concerned with the latter. Juniper Hill is one concrete example of successional change in plant dominance. It may well share the time scale for change with a majority of the existing western juniper woodlands that have invaded big sagebrush sites in the region. Many scientists have been preoccupied with the period 1890 to 1910, when the majority of the invasions occurred. However in a biological application of Hutton's law, what has happened before is happening now. Each year, juniper seedlings are establishing in big sagebrush communities, but their influence on succession and dominance will not be apparent to land managers for another 25 to 50 years.

A change in the frequency of wildfires is the most probable cause of juniper invasion of the big sagebrush sites, but our current methods for reconstructing fire histories are woefully inadequate for this type of woodlands. The upshot is that there is no simple, single factor that causes wholesale shifts in dominance of rangeland plant communities. Mehringer and coworkers' (1977) ideas for using the stratigraphy of microscopic charcoal deposits for indexing fire frequency may offer a solution to this important problem.

Literature Cited

Adams, A.W. 1975. A brief history of juniper and shrub populations in southern Oregon. Final Report on Federal Aid to Wildlife Restoration Project U-70-R. Oregon State Univ., Corvallis, 33 p.

Arno, S.F., and K.M. Sneck. 1977. A method for determining fire history in coniferous forest of the mountain West. U.S. Forest Serv., Intermountain Forest and Range Exp. Sta., General Tech. Rep. INT-42. 28 p.

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

Bruner, A.D., and D.A. Klebenow. 1979. Predicting success of prescribed fires in pinyon-juniper woodland in Nevada. U.S. Forest Serv., Res. Pap. 219. 11 p.

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

Caraher, D.L. 1978. The spread of western juniper in central Oregon, p. 3-7. *In:* Martin, R.E., J.E. Dealy, and D.L. Caraher (Eds.) Proc. Western Juniper Ecology and Management Workshop. U.S. Forest Serv., General Tech. Rep. PNW-74.

Douglas, A.E. 1928. Climatic cycles and tree growth: A study of the annual rings of trees in relation to climate and solar activity. Carnegie Inst. Wash. Publ. 289. 166 p.

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

Guinn, A.M. 1906. History of the State of California and Biographical Records of the Sierra. Chapman Publ. Co., Chicago. 781 p.

Harper, J.L. 1977. Population Biology of Plants. Academic Press, London. 892 p.

Herbst, J.R. 1977. Physical properties and commercial uses of western juniper, p. 169-177. *In:* Martin, R.E., J.E. Dealy, and D.L. Caraher (Eds.) Proc. Western Juniper Ecology and Management Workshop. U.S. Forest Serv., Pacific Northwest Forest and Range Exp. Sta.

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

King, P.B. 1959. The Evolution of North America. Princeton University Press, Princeton, New Jersey.

Mehringer, P.J., Jr., S.R. Arno, and K.L. Peterson. 1977. Postglacial history of Lost Trail Pass Bog, Bitterroot Mountains. Montana Arctic Alpine Res. 9:345-368.

Sudworth, G.B. 1908. Forest trees of the Pacific Slope. U.S. Forest Serv., Washington, D.C.

Vasek, F.C. 1966. Distribution and taxonomy of three western junipers. Brittonia 183:350-372.

Young, J.A., and R.A. Evans. 1971. Medusahead invasion as influenced by herbicides and grazing low sagebrush sites. J. Range Manage. 23:451-454.