

1987, Miller et al. 2000). Most of the 9 million acres occupied by western juniper is still in transition from shrub-steppe to western juniper woodland (Miller et al. 2000) and the species continues to expand its range and increase in density (Miller and Rose 1995, 1999; Knapp and Soulé 1998; Wall et al. 2001), even in the absence of livestock grazing (Soulé et al. 2004).

Factors affecting post-settlement expansion

Factors most frequently attributed to the increase in both density and area of piñon and juniper are climate, the introduction of livestock, industrial increases in atmospheric CO₂, and the reduced role of fire (Fig. 4).

Climatic influences

From 1850 to 1916, winters became milder and precipitation was greater than the current long-term average in much of the Great Basin (Antevs 1938, Wahl and Lawson 1970, LaMarche 1974, Graumlich 1987). There is some indication that woodland expansion was initiated between 1850 and 1870 in some areas prior to European settlement (Fig. 3b) (P.E. Mehringer, Department

of Anthropology and Geology, Washington State University, personal communication; Johnson 2005). However, expansion across the majority of areas sampled occurred in the late 1800's (Table 2; Fig. 3a, c, d). Annual tree ring growth in western juniper is strongly related to local climatic conditions (Pohl et al. 2002). Soulé et al. (2004) reported that western juniper annual ring growth across five sites in eastern Oregon were above-average from the late 1800's through the early 1900's. This wet period coincides with post-settlement establishment and the peak period of woodland establishment for closed stands (Table 2). Wet, mild conditions promote vigorous growth in western juniper (Fritts and Wu 1986, Holmes et al. 1986).

Livestock grazing

Introduction of livestock in the 1860's and the large increase of animals from the 1870's through the early 1900's (Oliphant 1968, Miller et al. 1994) coincide with the initial expansion of western juniper woodlands. Season-long grazing by the large numbers of domestic livestock during this period is believed to have reduced fine fuel loads, thus contributing to a significantly reduced role of fire in the northern Great Basin (Burkhardt and Tisdale

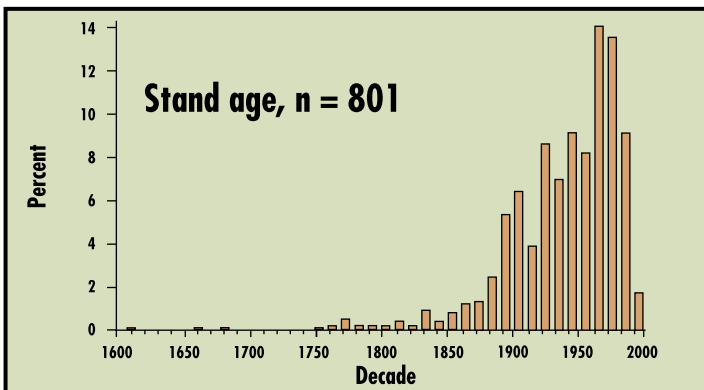


Figure 3a. Lava Beds National Monument in northern California.

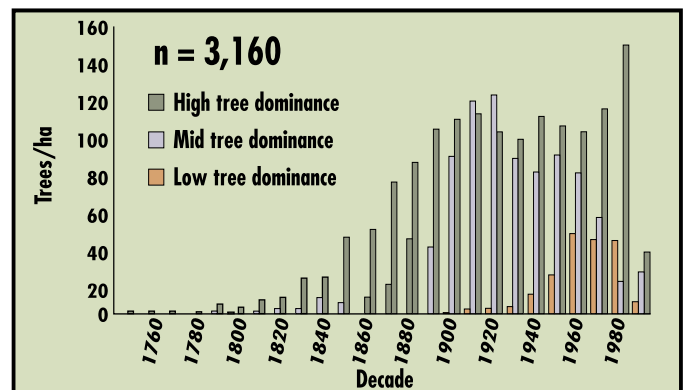


Figure 3b. Combined chronologies from 42 miles of transects in Steens Mountain south-eastern Oregon, and South Mountain and Juniper Mountain in southwestern Idaho.

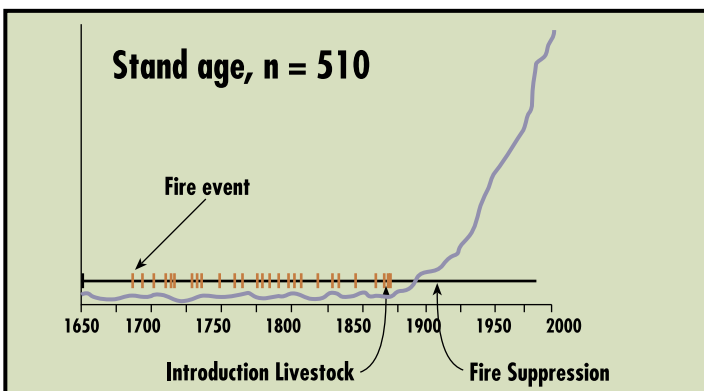


Figure 3c. Chewaucan River basin in the Paisley Ranger District, Fremont National Forest in south-central Oregon.

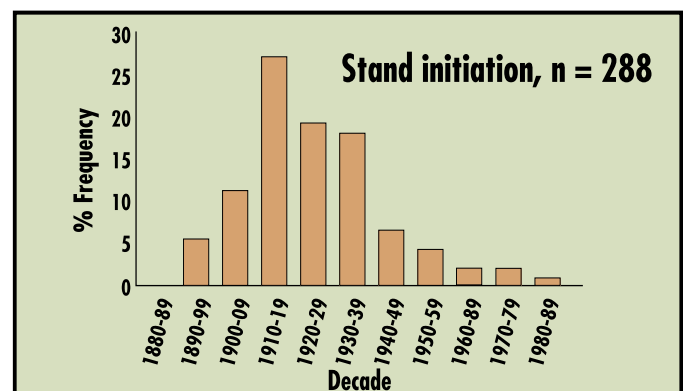


Figure 3d. When juniper encroachment began (based on the three oldest western juniper in the stand) in 96 aspen stands in southeastern Oregon, northeastern California, and northwestern Nevada. Chronologies are based on tree ring data.

1976, Miller and Rose 1999, Miller and Tausch 2001). Fire occurrence and fire size declined dramatically in the late 1800's. Miller and Rose (1999) reported a large decrease in fire occurrence in southeastern Oregon shortly after large numbers of livestock were introduced in the late 1860's (Fig. 3c). The lack of fire and decreased competition from herbaceous species probably contributed to an increase in shrub density and cover, thus providing a greater number of safe sites for western juniper establishment (Miller and Rose 1995, 1999). The role of livestock as a mechanism for western juniper seed dispersal appears to be minimal (Burkhardt and Tisdale 1976).

Atmospheric CO₂

Rising levels of atmospheric CO₂ seem to have enhanced the increase in woody species throughout the West (Johnson et al. 1993, Knapp and Soule 1999b). Increases in atmospheric CO₂ levels do not coincide with the initial increase or peak periods of western juniper establishment (Table 2). However, elevated atmospheric CO₂ during the last half of the 20th century may be an important contributing factor accelerating tree canopy expansion and establishment in some areas (Knapp and Soule 1996, 1998, 1999b; Soule et al. 2004). Annual sapwood growth in western juniper has been significantly greater since the 1950's compared to prior years (Knapp et al. 2001a, b), suggesting accelerated growth. The authors suggest elevated CO₂ levels may have a drought-ameliorating effect by increasing water use efficiency.

Fire

Fire is considered to have been the most important factor in limiting conifer encroachment into shrub-grassland communities in the Intermountain West prior to European settlement (West 1999, Miller and Tausch 2001). However, only a few studies have documented fire regimes across shrub-steppe communities and woodlands throughout this region. Unlike ponderosa pine, junipers seldom repeatedly scar in response to fire; thus it is difficult to determine or describe presettlement fire regimes across many shrub-steppe and woodland communities. Fire scars on western juniper are occasionally found, but most presettlement trees do not grow on sites representative of more productive deeper-soil sites, which now support expanding post-settlement woodlands. Old-growth western juniper is commonly found on relatively fire-safe sites (i.e., rocky surfaces, shallow soils, limited effective moisture) characterized by low production with limited fine fuels (Burkhardt and Tisdale 1976; Vasek and Thorne 1977; Young and Evans 1981; Holmes et al. 1986; Miller and Rose 1995, 1999). Evidence that woodland expansion was limited by fire events prior to settlement includes: (1) sites supporting old-growth trees are usually fuel-limited,

(2) most young stands occupy the more productive communities where fine fuel loads could carry a fire, and (3) the time sequence of woodland expansion is synchronous with the decline in fire occurrence.

In productive mountain big sagebrush plant associations in the Northwest, such as those characterized by Idaho fescue (*Festuca idahoensis*), MFRIs (mean fire return intervals⁸) typically ranged between 10 to 25 years (Table 3) and large fires every 38 years. Potential natural vegetation resulting from these short fire return intervals would probably have been dominated by Idaho fescue with an open, scattered canopy of mountain big sagebrush. MFRIs were determined from fire scars collected on ponderosa pine or Douglas-fir (*Pseudotsuga menziesii*) growing in or adjacent to mountain big sagebrush communities (Fig. 5). In two studies, where presettlement MFRIs were 12–15 years, fire-free intervals varied between 3 and 29 years (Gruell 1999, Miller and Rose 1999). However, fire occurrences were less frequent in the more arid plant associations in the mountain big sagebrush alliance. Based on tree growth, age structure, and the scarcity of presettlement trees or the presence of large dead wood, the maximum MFRIs in the mountain big sagebrush/Thurber needlegrass (*Stipa thurberiana*) plant association was probably 50–70 years. Fire return intervals up to 50 years were probably adequate to limit western juniper encroachment into the mountain big sagebrush alliance (Burkhardt and Tisdale 1976, Miller and Rose 1999). The probability that western juniper will establish and successfully mature greatly increases

⁸MFRIs = arithmetic average of the number of years between fire events determined for a designated area during a designated time period.

Figure 4. Conceptual model illustrating factors influencing the expansion of western juniper since the late 1800's and throughout the 1900's (Miller and Tausch 2001).

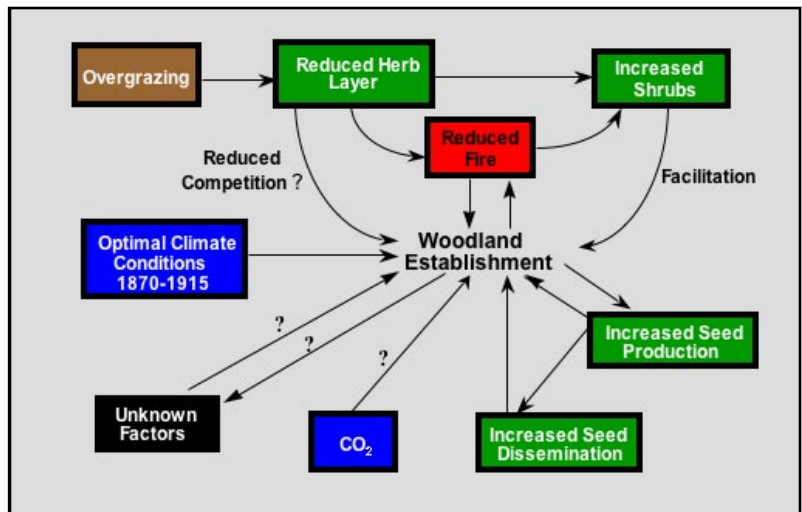


Table 3. Presettlement mean fire-return intervals (MFRI = average number of years between fire events) in sagebrush and aspen cover types associated with western juniper. Change indicates the decade when the MFRI increased (Miller and Tausch 2001).

Plant Association	MFRI (yrs)	Decade of change	Location	Reference
Mountain big sagebrush/				
Idaho fescue	20	Late 1800's	Lava Beds National Monument, CA	Martin & Johnson 1979
	11	1910	Owhyee Mt, ID	Burkhardt & Tisdale 1976
Idaho fescue	12–15	1870's	Chewaucan–Paisley, OR	Miller & Rose 1999
Idaho fescue	13	Late 1800's	Hart Mt, OR	Gruell 1999
Idaho fescue	13–15	1870's	Pine Mt, OR	Miller et al. 2001
Idaho fescue	16	1860's	Summer & Silver Lake, OR ¹	Miller et al. 2001
Idaho fescue	12	1880's	Fort Rock, OR ¹	Miller et al. 2001
Idaho fescue	17	1870's	Devils Garden, CA	Miller et al. 2001
Idaho fescue	6	1870's	Silver Lake, OR ¹	Miller et al. 2001
Idaho fescue	16.5		Silver Lake northwest, OR ¹	Miller et al. 2001
Idaho fescue, with some ponderosa pine	8–10	1870	Lava Beds National Monument, CA	Miller et al. 2003
Western Juniper/				
western needlegrass	150+		Lava Beds National Monument, CA	Miller et al. 2003
Low sagebrush/				
Not reported		1860	northwestern CA	Young & Evans 1981
Sandberg bluegrass	138	1870	Chewaucan–Paisley, OR	Miller & Rose 1999
Aspen				
	60 ²	1870's	eastern OR, northeast CA, & northwest NV	Wall et al. 2001

¹General location of stand studied.

²Stand replacement interval based on aspen age structure, disturbance may not be fire.

Figure 5. Ponderosa pine with over a dozen pre-1900 fire scars in a densely wooded community at Lava Beds National Monument, northeastern California. The pre-1900 plant community was an open ponderosa pine stand with an understory dominated by Idaho fescue. The mean fire return interval was between 8 to 15 years. The stand is now dominated by western juniper (greater than 100 trees/acre) and mountain mahogany soon to be overtaken by western juniper (greater than 100 trees/acre).



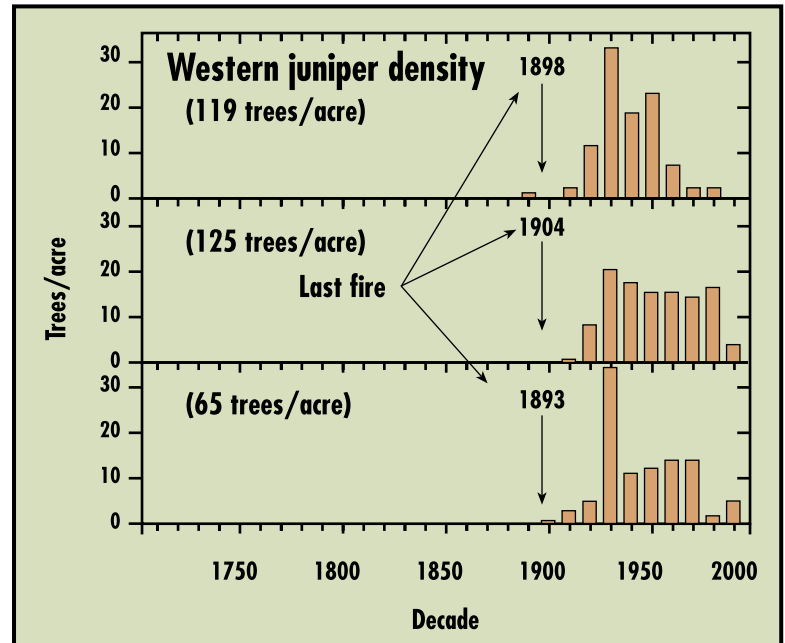
as MFRIs become more than 70 years. A fire free period of more than 70 years will also increase the potential for leaving large-diameter charred wood consisting of heartwood (that can persist on the site for more than 100 years), resulting from the development of mature trees on the site. Small trees consisting of mostly sapwood usually decompose in several decades. In northern California, a plant community identified as a western juniper/mountain big sagebrush/western needlegrass (*Stipa occidentalis*) plant association burned in 1856 (Miller et al. 2003). Intact charred wood and fire-killed trees are still present on the site. On Juniper Mountain in eastern Oregon, trees killed by fire in 1717 still persist in the stand.

A number of studies in mountain big sagebrush communities in the Intermountain West have reported significant declines in fire events since the late 1800's (Table 3) (Miller and Tausch 2001). Several studies have shown a close relationship between the early expansion of western juniper in the late 1800's and the sudden decline in fire occurrences in the mountain big sagebrush alliance (Figs. 3c, 6) (Miller and Rose 1999; Miller et al. 2001, 2003).

MFRIs reported for the low sagebrush/Sandberg bluegrass (*Poa sandbergii*) association (Table 3) were considerably longer than for neighboring mountain big sagebrush communities (Young and Evans 1981, Miller and Rose 1999). Fire-free periods of 90 (Young and Evans 1981) and 138 years (Miller and Rose 1999) were reported for this plant association in northern California and south-central Oregon and it is not unlikely that fire-free periods exceeded 150 years for some sites. This plant association can be characterized by a low density of widely scattered old-growth western juniper, which suggests infrequent fires. Tree growth rates are relatively slow with the average age of a 3-m-tall tree ranging from 75 to 90 years. Fire return intervals of 100 to 150 years would probably be adequate to maintain a low-density stand of widely scattered trees in this plant association. In the absence of fire, western juniper will slowly increase in density in this plant association.

Fire also played an important role in the maintenance of healthy mixed-age aspen stands in the semi-arid West (Bartos and Campbell 1998). In the northwestern Great Basin, Wall et al. (2001) reported that encroachment of western juniper into these communities began around 1900. Fire was probably the primary disturbance factor limiting western juniper invasion into these aspen communities. Based on the composition and distribution of age of aspen in two large stands in southeastern Oregon, presettlement mean

Figure 6. Tree densities and age chronologies of western juniper and date of last fire for three cinder buttes sampled on the Lava Beds National Monument, northern California. The lack of large dead juniper wood on these sites suggests mature juniper did not occupy these sites prior to 1900. Potential natural vegetation is Idaho fescue grassland with widely scattered ponderosa pine and mountain big sagebrush and mean fire return interval prior to 1900 was 8–10 years (Miller et al. 2003).



disturbance intervals were determined to be 16 years within portions of these stands. Wall et al. (2001) estimated that total stand replacement in these two aspen communities occurred around 60–100 year intervals.

Climate and fire

In eastern Oregon, large presettlement fires in sagebrush-steppe communities were usually preceded by at least one year of above-average growing conditions (Miller and Rose 1999). In these semi-arid ecosystems, fuels are often limited in abundance and continuity. A series of wet years allows fuels to accumulate and become more contiguous. Wetter than average conditions in the late 1800's would have resulted in the accumulation of fine fuels. However, high livestock stocking rates and season-long or heavy grazing during this period reduced fine fuel accumulations and thus significantly decreased the potential for fire (Burkhardt and Tisdale 1969, Miller and Rose 1999). The combination of reduced fire occurrences (Miller and Tausch 2001) and optimal climatic conditions for conifer establishment (Fritts 1974, Fritts and Wu 1986) at the turn of the century were probably the two dominant factors that initiated post-settlement western juniper expansion.