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Western juniper expansion on adjacent disturbed and near-relict sites

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Abstract

We determined rates of western juniper (*Juniperus occidentalis* spp. occidentalis Hook.) density and cover change during the period 1951 to 1994 at 3 adjacent sites with nearly identical elevation, slope, aspect, soils, plant communities, and climate, but different land-use histories. The 3 sites are located in central Oregon at the confluence of the Deschutes and Crooked Rivers. Two of the sites are typical of central Oregon rangelands in that they have a history of anthropogenic disturbance including active fire suppression and domestic livestock grazing. The third site is a relict mesa that is a protected Research Natural Area and has experienced minimal anthropogenic impacts. We used large scale aerial photography to determine cover and density of western juniper in 1951, 1956, 1961, 1972, 1982, and 1994. We found that western juniper density and cover during the last 4 decades increased at all sites, with changes on the relict site similar to those on one of the disturbed sites. We suggest that even though 2 of the traditionally cited causes of western juniper expansion since the late 1800s (altered fire regimes, domestic livestock grazing) may have contributed to expansion on our disturbed sites, these mechanisms can not explain expansion on the near-relict mesa. Further, we examined climatic changes since 1900 in the region and concluded that the data did not fully support a climate-driven mechanism for the expansion. In seeking to explain western juniper expansion on semiarid rangelands, we suggest that all potential causal mechanisms (e.g., fire history, biological inertia, climate, domestic grazing, atmospheric CO_2 enrichment) be considered.

Key Words: afforestation, central Oregon, land-use history, biological inertia

Resumen

Determinamos las tasas de densidad y cambio de cobertura del "Western Juniper" (*Juniperus occidentalis* spp. Occidentalis Hook.) ocurridas durante el período de 1951 a 1994 en 3 sitios adyacentes con elevación, pendiente, aspecto, suelos, comunidades vegetales y clíma casi idénticos pero con diferentes historias de uso de la tierra. Los 3 sitios se localizan en la parte central de Oregon en la convergencia de los ríos "Deschutes" y "Crooked". Dos de los sitios son típicos de los pastizales centrales de Oregon, los cuales tienen una historia de disturbio antropogénico incluyendo la supresión activa de fuego y el apacentamiento de ganado. El tercer sitio es un área natural reliquia protegida y para fines de investigación, y que ha experimentado impactos antropogénicos mínimos. Utilizamos fotografía aérea a gran escala para determinar la cobertura y densidad del "Western Juniper" en 1951, 1956, 1961, 1972, 1982 y 1994. Encontramos que en las últimas 4 décadas la densidad y cobertura del "Western Juniper" ha incrementado en todos los sitios, presentando el área reliquia cambios similares a los ocurridos en uno de los sitios con disturbio. Sugerimos que a pesar de que las 2 causas (supresión de fuego y apacentamiento de ganado domestico) tradicionalmente citadas como responsables de la expansión del "Western Juniper" ocurrida desde finales del siglo pasado pueden haber contribuido a la expansión en los dos sitios con disturbio; sin embargo, estos mecanismos no pueden explicar la expansión ocurrida en el área reliquia. Además, examinamos los cambios climáticos ocurridos en la región desde 1900 y concluimos que los datos no sustentan por completo una expansión inducida por el clíma. Sugerimos que en la búsqueda de la explicación de la expansión del "Western Juniper" en los pastizales semiáridos, se deben consider todos los mecanismos causales potenciales (por ejemplo, historia de fuego, inercia biológica, clíma, apacentamiento de ganado doméstico, incremento del CO_2 atmosférico).

Western juniper (*Juniperus occidentalis* spp. occidentalis Hook.) is the dominant tree of arid and semiarid Pacific Northwest woodlands (Agee 1993). Found in California, Idaho, Nevada, Oregon, Washington, it has undergone substantial afforestation during the last century, including increases in density and cover on previously occupied sites, and an approximate doubling of its range (Caraher 1978, Miller et al. 1987, Bedell et al. 1993). While older stands of western juniper are largely found on areas with "deep pumice sands", "rock outcrops," and "shallow soils underlain by deeply fractured bedrock," the new woodlands are expanding into areas previously dominated by shrubs (e.g., *Artemesia tridentata* Nutt.-big sagebrush) and grasses (e.g., *Festuca idahoensis* Elmer.-Idaho fescue, *Agropyron spicatum* (Pursh) Scribn. & Sm.-bluebunch wheatgrass) (Bedell et al. 1993:4). There is concern that the rapid rate of expansion may result in western juniper super dominance in communities previously

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dominated by big sagebrush (Liverman 1993), and that juniper expansion may alter ecocsystem functioning via changes in species composition (e.g., Burkhardt and Tisdale 1969, Vaitkus and Eddleman 1991) and altered fire regimes (e.g., Burkhardt and Tisdale 1976, Agee 1993). It has been argued that these ecosystem alterations may result in the loss of wildlife habitat, reduced range productivity and diversity, and watershed degradation (Bedell et al. 1993, Liverman 1993). Others (e.g., Gifford 1987, Belsky 1996), however, have shown that some of the negative characteristics often associated with its expansion on the western range (e.g., decreased water infiltration, increased soil erosion, stream flow reduction, decreased wildlife habitat) are not fully supported.

Despite the uncertainty surrounding the ultimate consequences of western juniper expansion, it remains an issue with both ecological and management implications. Both the Oregon Department of Fish and Wildlife (ODFW) and the Bureau of Land Management (BLM) are interested in western juniper woodland management programs. Management projects proposed by the BLM would be extensive and expensive ($27,000,000+), involving selective cutting and prescribed burns on some 273,000+ ha of established and emerging juniper woodlands (Liverman 1993).

Dendrochronological studies have shown that historic western juniper expansion began in the late 1800s, and in the absence of reestablishment in sites of wood cutting the expansion has been chiefly linked with 3 causes: 1) reduction in fire frequency caused by organized fire suppression and/or by a reduction in fine fuels in areas of heavy livestock grazing; 2) the indirect effects of livestock grazing (e.g., fuel reduction and an increase in shrubby nurse plants); and 3) favorable climatic conditions (i.e., mild wet winters and cool wet springs) (Burkhardt and Tisdale 1976, Young and Evans 1981, Eddleman 1987, Miller and Rose 1995). However, none of the traditional explanations appear to be “entirely satisfactory in explaining” historic western juniper expansion (Young and Evans 1981:505). There is continued interest in examining the rates and probable causes of western juniper afforestation because: 1) the current expansion is occurring at geometric rates at some locales (Liverman 1993, Miller and Rose 1995), and 2) the causes of the current expansion are uncertain.

A rare opportunity to compare the effects of land-use history on western juniper expansion exists in central Oregon. At the confluence of the Deschutes and Crooked Rivers lie 3 sites of nearly identical elevation, slope, aspect, soils, plant communities and climate (Fig. 1). This geographical setting allows for minimizing the biotic and abiotic differences between sites that in turn provides for a more direct comparison of the effects of past land-use history. Further, large-scale aerial photography of all 3 sites exists from 1951 through 1994. Thus, the purpose of this paper is to: 1) document rates of western juniper expansion (i.e., density and cover increases) during the last 4 decades, and 2) address how land-use histories may have affected western juniper expansion on the 3 sites.

Study Site Characteristics

The Island Research Natural Area (IRNA) is a near-relict area managed by the Prineville District of the Bureau of Land Management (BLM), the Crooked River National Grasslands (part of the Ochoco National Forest), and Oregon State Parks. Because of its classification as a Research Natural Area, anthropogenic disturbances at IRNA are limited. Grazing is not allowed, fire suppression is not active, and the plateau is controlled by Oregon State Parks personnel with usage limited to scientific and educational activities. The area has not been grazed for over 70 years, and the only historical account of livestock grazing was for sheep during 2 consecutive summers sometime between 1922 and 1928 (Driscoll 1964).

Both the Canadian Bench and Western Peninsula are more typical of central Oregon rangelands in terms of their disturbance history and current use. Grazing is active on both sites (B. Cheney, Ochoco National Forest, pers. comm. 1995, S. Lusk, Ochoco National Forest, pers. comm. 1995, field reconnaissance 1997). For example, in 1994 there were 100 head of cattle grazing in the area containing the Canadian Bench study site and from the early to mid 1980s there also was horse grazing on the Canadian Bench. Horse Grazing on the Canadian Bench resumed again during the winter of 1994–1995. Records indicate that grazing on the Western Peninsula has been exclusively cattle since 1960 and an analysis of aerial photographs shows that an unimproved road was developed on the Western Peninsula study site sometime between 1961 and 1972. Although we know both sites have been grazed since 1960, it is not possible to reconstruct fully the domestic grazing history of either site beyond 1960 because of a lack of records. However, we do know that all but the most inaccessible central Oregon rangelands (e.g., the Island Research Natural Area) have been grazed intermittently since the late 1880s (Hopkins and Kovalchik 1983), so it is logical to conclude that both the Western Peninsula and Canadian Bench have been impacted by domestic grazing, at least intermittently, for over a century. In addition, we know that homesteading occurred in the area containing the Canadian Bench and Western Peninsula from the 1880s till the 1930s, and range conditions may have been altered by other anthropogenic activities such as prescribed fires, cutting and chaining of juniper, and seeding (e.g, some of the range in the area including the Canadian Bench was seeded with crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) in the 1930s and the 1960s).

The 3 study sites lie in a Fire Occurrence Zone of .03 to .07 fires/405 ha/yr, which places them in a low to medium range (K. Donham, Ochoco National Forest, pers. comm. 1995). However, large hot fires, such as the Little Cabin wildfire of August 1996 that burned 987 ha on land adjacent to the study sites before being contained, do occur within the region. Organized fire suppression is active on both the Western Peninsula and Canadian Bench, but not active on the Island Research Natural Area. National Fire Management Analysis fire records extend back to 1970, and these records show no fires on the 3 sites. However, interviews with personnel from the BLM, the Ochoco National Forest, and rangers at Cove Palisades State Park (which includes the Island Reseach Natural Area) revealed that 2 fires occurred on the Island Research Natural

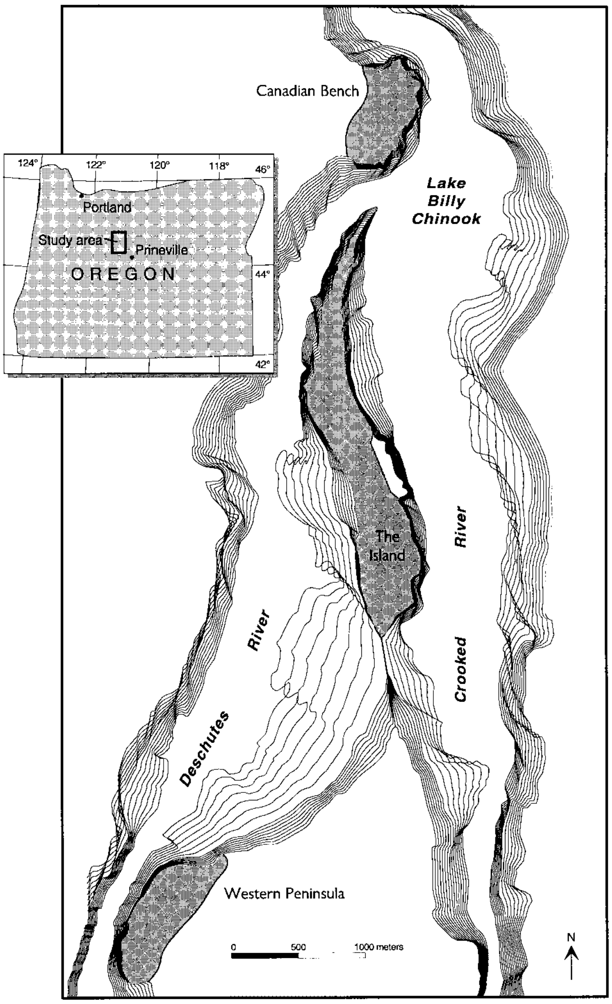

Fig. 1. Location of study sites and Prineville.

Area between 1970 and 1994, both on the same day in late August 1987. One fire burned an individual juniper before extinguishing, the second burned one-thirtieth of a hectare (Knapp and Soulé 1996).

Because all 3 sites are largely flat, at the same elevation (730 m), and separated by less than 3 km, their macroclimates should be identical. Records from Prineville, Ore. (Fig. 1) show the climate to be semiarid, with annual means of 25 cm for precipitation and 8.5°C for temperature. Prineville temperatures range from a mean of 18.1°C in July to –0.4°C in January, and precipitation ranges from a low of 0.99 cm in July to a maximum of 3.05 cm in November (Karl et al. 1990).

Soils characteristics on the 3 sites are similar, with loess as the parent material, thick loams (25 cm–40 cm) for the topsoil and subsoil, a topsoil to subsoil ratio of 0.5/1, and 1–2% organic matter (USDA-NRCS in press). The soil series for the Canadian Bench and Western Peninsula is Agency Madras, and for the Island Research Natural Area it is Agency Sandy. The 3 sites all support a *Juniperus occidentalis, Artemesia tridentata, Agropyron spicatum* plant community (Franklin and Dyrness 1988). On the Island Research Natural Area this is the dominant plant community, covering the 67 ha examined in this study. It is the sole community on the 29 ha examined on the Canadian Bench and the 34 ha examined on the Western Peninsula.

One change in the local environment occurred in 1963 with the damming of the Crooked and Deschutes Rivers to create Lake Billy Chinook. As detailed by Knapp and Soulé (1996), it is unlikely the creation of this lake altered the microclimate of the region in any manner significant to vegetation growth.

Methods

Vegetation

Using techniques detailed by Knapp et al. 1990, we monitored changes in both cover and density of trees through time using large scale (1:12,000 to 1:19,900) aerial photographs of the 3 study sites for the years 1951, 1956, 1961, 1972, 1982, and 1994. For each year and for each site the boundaries were delineated and 3 separate counts of western juniper density were made, with the average of the 3 counts presented in per hectare format. Scale limitations of the aerial photographs limit the density and cover measurement to mature western juniper. These observations are possible because of the uniformity of the vegetation associations and the lack of tree species diversity on the 3 sites.

Western juniper cover also was measured for each site and year using the dot-grid method (Poulton 1975). A dot grid (11 dots/cm^2) was overlaid on the photos. Each time a dot intersected a juniper the point was recorded. The total number of intersected dots (those overlaying or intersecting western juniper) divided by the total number of dots in the study area provides the cover estimate in percent. Three counts were made for each photograph, with cover being presented as the average of the 3.

Climate

To characterize climate, data from the Prineville 4NW station were used. Approximately 43 km to the southeast and 140 meters higher, Prineville 4NW is the closest and most comparable site in the Historical Climate Network database (Karl et al. 1990). Historical Climate Network data are desirable because of their high level of quality control and because they are corrected for biases (e.g., time of observation bias) that exist in most temperature and precipitation data sets for United States stations (Karl et al. 1990). Monthly temperature and precipitation data were compiled for the period July 1900 to June 1995. Missing data (<1.2%) were replicated as described by Knapp and Soulé (1996). We examined seasonal water year (July to June) and winter (November to February) trends for 1900–1994, for the period corresponding to our aerial photographs (1950–1994), and the prior period (1900–1949). We used November to February as winter because this includes 3 of the 4 wettest months (November, December, January) and accounts for 44% of annual precipitation, on average. We used linear regression to establish the direction of trend (e.g., Karl and Heim 1990, Plantico et al. 1990, Idso and Balling 1992, Soulé and Yin 1995), and tested for significance using rank correlation (Yin 1993). We tested for significant differences in seasonal water year and winter precipitation and temperature between the time period corresponding to aerial photographs (1950–1994) and the prior time period of available climate data (1900–1994) using the Wilcoxon Ran Sum W Test, a null hypothesis of no significant difference, and $\alpha = 0.05$.

Results

Vegetation

Density of mature western juniper increased at all sites from 1951 to 1994 (Figs. 2–5). The smallest absolute increase (3.13 trees/ha from 1951 to 1994, 210 trees total) occurred on the least disturbed site (the Island Research Natural Area). While the per hectare increase is nearly identical to that observed on the Western Peninsula (3.15 trees/ha, 107 trees total), the change in juniper density at the Canadian Bench (6.83 trees/ha, 198 trees total) is more than double that found at either the Island Research Natural Area or Western Peninsula. Absolute cover also increased from 1951 to 1994 at all sites, with the largest changes again found on the Canadian Bench (Fig. 6). Absolute cover changes at the Island Research Natural Area (3.3% increase from 1951 to 1994) were again more comparable to those observed on the Western Peninsula (4.8%) than the Canadian Bench (8.0%), but the relative (to 1951) cover changes were largest at the Western Peninsula (117% increase) and most similar between the Island Research Natural Area (60%) and the Canadian Bench (69%).

Climate

Long-term trends (1900–1994) of seasonal water year (SWY) precipitation are significantly upward, and both seasonal water year and winter precipitation are significantly greater in the 1950–1994 period compared to 1990–1949 (Table 1). However, within the time period corresponding to aerial photography analysis (1950–1994), precipitation is constant, and temperature is trending upward significantly (Table 1, Figs. 7 and 8). Winter precipitation is also greater from 1950–1994 than from 1900–1949 (Table 1), and winter temperature trends are nearly flat for all 95 years (Figs. 7 and 8). No significant differences were found for seasonal water year or winter temperatures between the 1950–1994 and 1900–1949 periods (Table 1).

Discussion

Traditionally-cited causal mechanisms for western juniper expansion

Lack of fire is one of the 3 traditional mechanisms cited for western juniper expansion

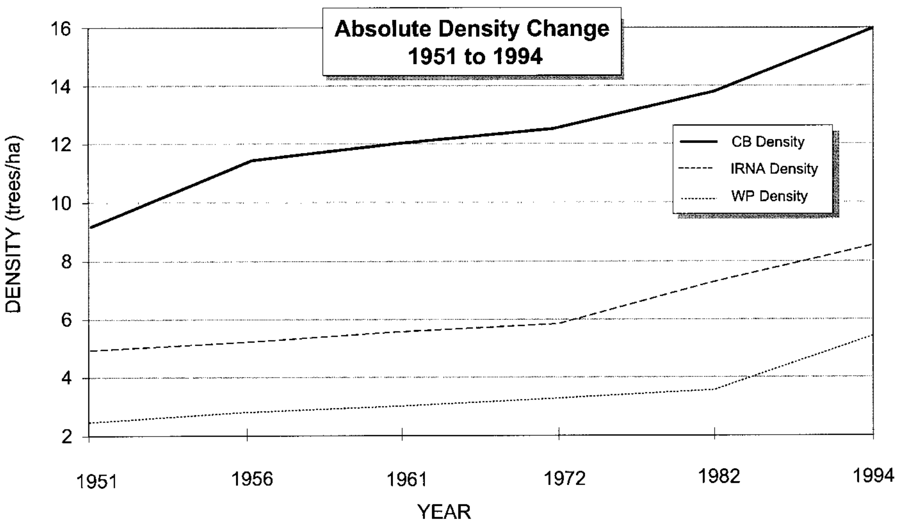

Fig. 2. Density changes of mature western juniper at the study sites from 1951 to 1994.

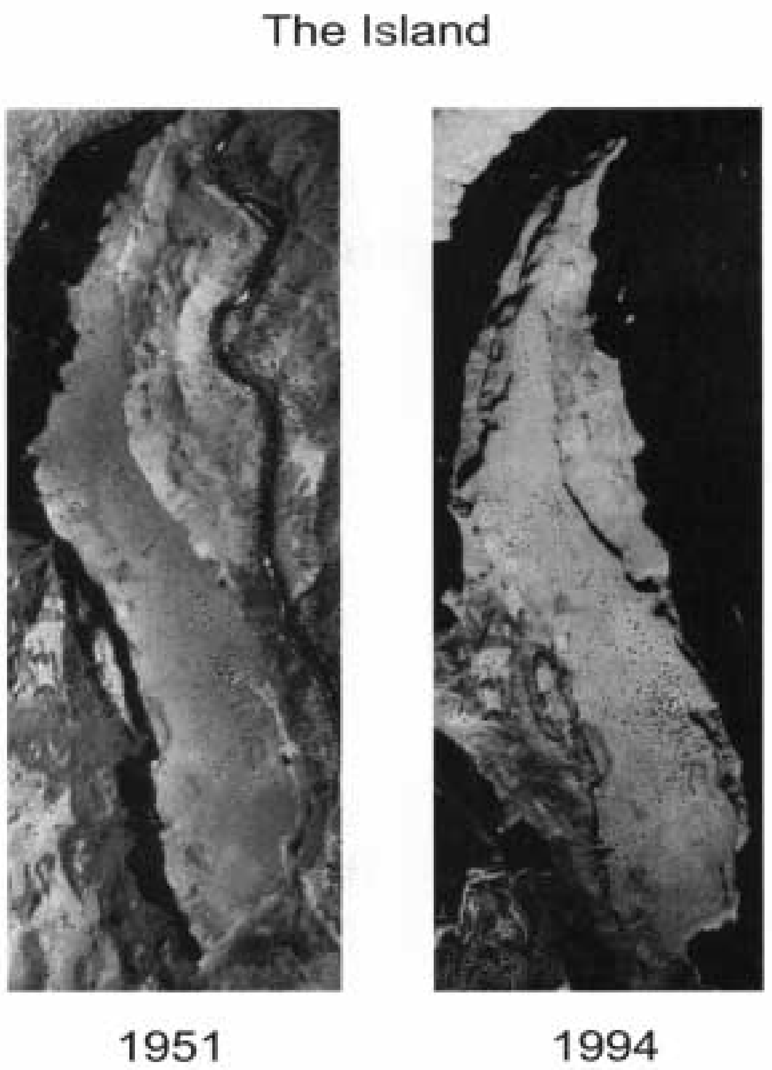

Fig. 3. Scanned images of black-and-white aerial photographs of the Island Research Natural Area for 1951 and 1994.

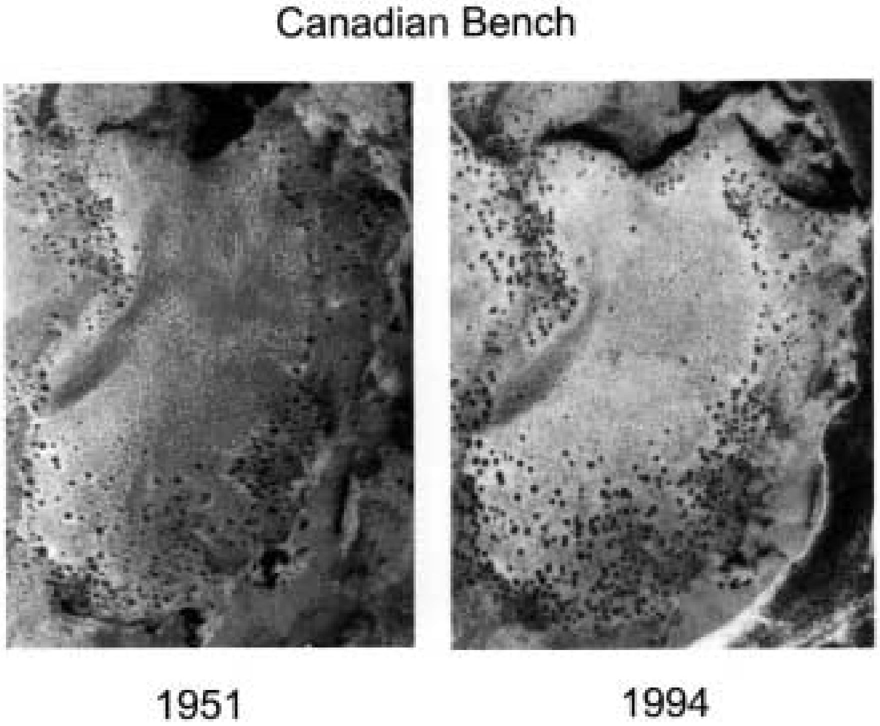

Fig. 4. Scanned images of black-and-white aerial photographs of the Canadian Bench for 1951 and 1994.

that may have impacted our study sites. Western juniper is a "fire avoider" and tree mortality is high during the seedling and sapling stage (Agee 1993:385). Field reconnaissance of the area burned in the Little Cabin fire of 1996 showed almost complete mortality of western juniper of all ages. Clearly there have been no fires of this magnitude on the 3 sites during the time period of available aerial photographs (1951–1994), and a lack of large numbers of burned stumps on the sites suggests the fire-free interval (for major fires) extends well before 1950. While the lack of grazing on the Island Research Natural Area should lead to a differential susceptibility to fire, the fire history of the past half century or more appears to have been equally beneficial to wesern juniper expan-

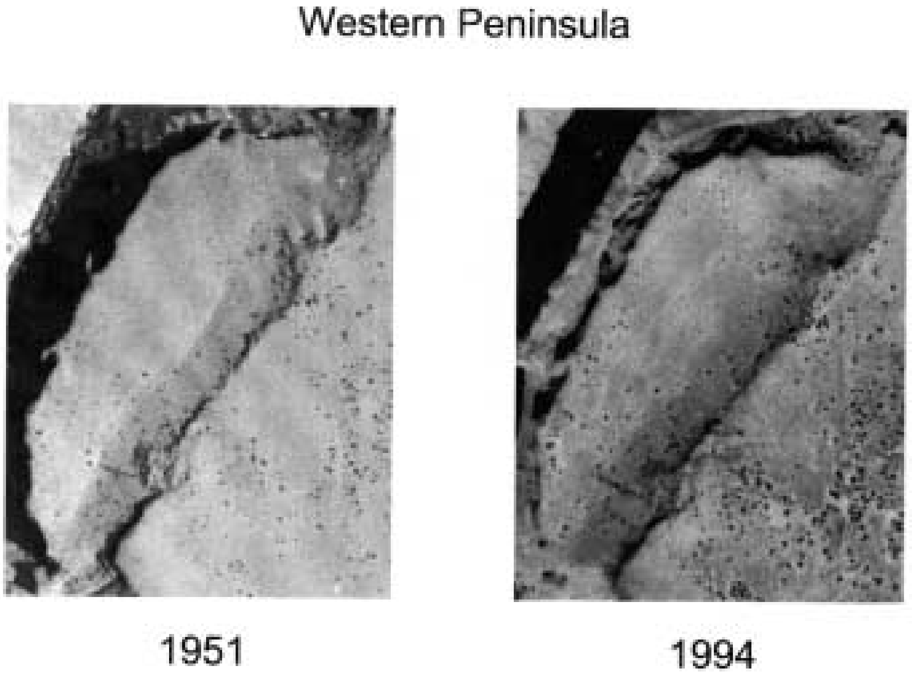

Fig. 5. Scanned images of black-and-white aerial photographs of the Western Peninsula for 1951 and 1994.

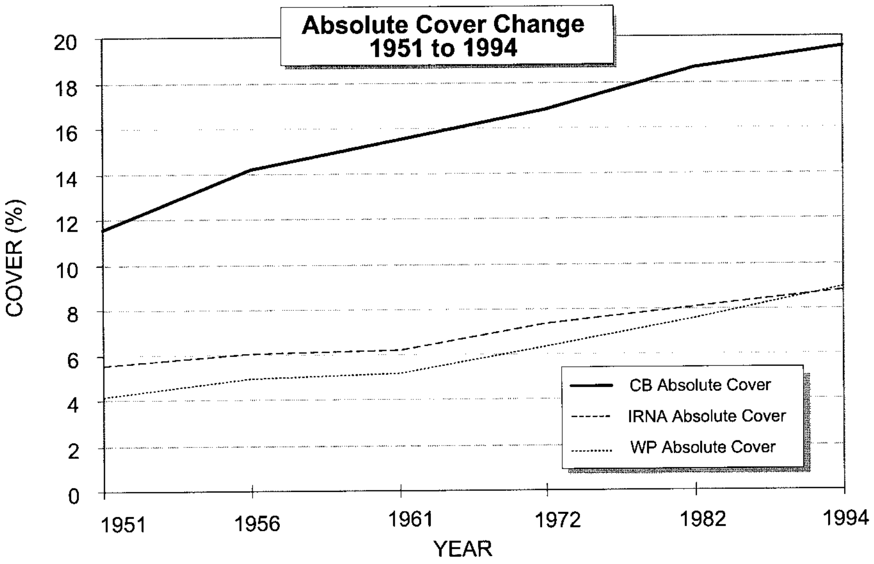

Fig. 6. Cover changes of mature western juniper at the study sites from 1951 to 1994.

sion on all 3 sites. Additional evidence suggests that altered fire regimes (fuel reduction from domestic livestock grazing and/or fire suppression) are not required for juniper expansion, since expansion and contraction of western juniper range and density occurred for several millennia prior to widespread anthropogenic activities (Miller and Wigand 1994).

Livestock grazing on the Canadian Bench and Western Peninsula may have influenced increases in western juniper density and cover by reducing perennial grass cover, thereby altering fire regimes (Miller et al. 1994) and perhaps improving juniper seedling establishment via a decrease in interspecific competition (in Miller et al. 1994). Archer (1994:13) has chiefly implicated livestock grazing as the "primary force" for causing woody plant invasions into southwestern grasslands and savannas and suggested that the greatest influence of livestock grazing on woodland encroachment may be on the establishment of woody plant seedlings. While there is little evidence that reduced perennial grass cover competition has facilitated western juniper establishment (Burkhardt and Tisdale 1976, Young and Evans 1981, Miller et al. 1994), it has been suggested that increased *Artemesia tridentata* cover has favored juniper seedlings by creating preferential microclimatic habitats (Eddleman 1987). Expansion of shrubs does occur in the absence of grazing in central Oregon, as Knapp and Soulé (1996) reported a near doubling of *Artemesia tridentata* cover from 1960 to 1994 on the Island Research Natural Area. While livestock grazing cannot adequately explain changes in western juniper density and cover on the Island Research Natural Area, these results are consistent with other findings (e.g., Anderson and Holte 1981, Goldberg and Turner 1986, Knapp and Soulé 1998) in that ongoing grazing is not a required mechanism to promote increasing woodiness on arid western rangelands.

The analyses of macroclimatic conditions provide mixed results. Miller and Rose (1995) speculate that the wetter, milder winters that occurred from 1850 to 1916 helped sustain growth and were a contributing factor to historic western juniper expansion in southeastern Oregon. Our analyses of precipitation at Prineville show that winter precipitation was significantly higher in the 1950–1994 period compared to the 1900–1949 period, a situation potentially beneficial to increased growth in the later half of the century. However, the

Table 1. Characteristics, trends, and time period comparisons for seasonal water year (SWY) and winter (Win.) temperature and precipitation. Data are from the Prineville 4NW station.

Time Period	Wilcoxon Test p-value	Variable	N	Mean	Regression SD	Spearman Slope	Spearman rs	p-value rs
precipitation:			(mm)					
1900–1994		SWY ppt	95	25.0	6.5	0.0515	0.22	0.035
1900–1949		SWY ppt	50	23.4	5.1	0.0243	0.08	0.583
	0.018							
1950–1994		SWY ppt	45	26.7	7.5	–0.0415	–0.06	0.689
1900–1994		Win. ppt	95	10.9	4.1	0.0271	0.20	0.051
1900–1949		Win. ppt	50	9.8	3.5	–0.0109	–0.07	0.643
	0.005							
1950–1994		Win. ppt	45	12.1	4.5	–0.0652	–0.18	0.233
temperature:			(°C)					
1900–1994		SWY temp	95	8.5	0.7	0.0009	0.05	0.623
1900–1949		SWY temp	50	8.4	0.8	–0.0213	–0.39	0.006
	0.260							
1950–1994		SWY temp	45	8.5	0.6	0.0164	0.34	0.021
1900–1994		Win. temp	95	1.5	1.4	–0.0002	0.07	0.514
1900–1949		Win. temp	50	1.3	1.3	–0.0273	–0.28	0.052
	0.060							
1950–1994		Win. temp.	45	1.7	1.4	–0.0197	–0.13	0.405

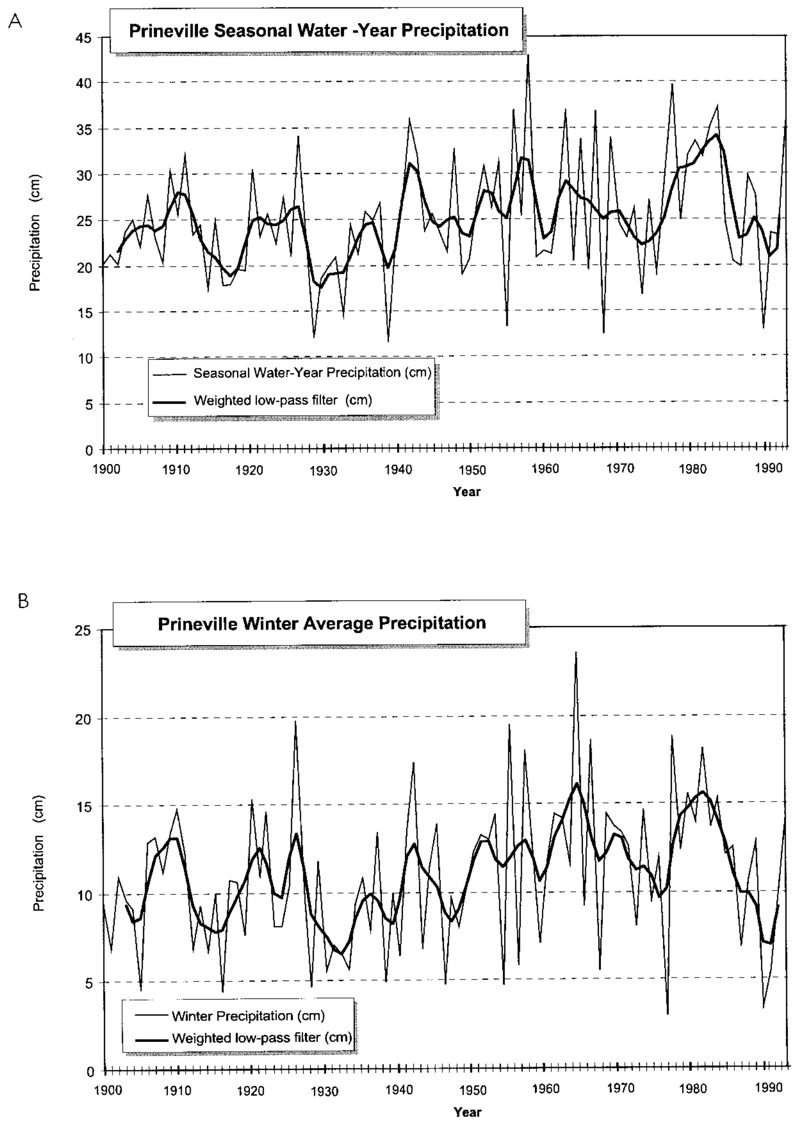

Fig. 7. Seasonal water-year precipitation and winter precipitation for Prineville, Ore.

later period displays considerable inter-yearly and inter-decadal variability, with 2 periods (mid 1960s–late 1970s; 1980s) of sharply falling winter precipitation, and the 2 driest winters since 1900 (1976, 1989)

Despite higher mean precipitation values in the 1950–1994 period, the data do not appear to implicate climatic conditions as a major cause of juniper expansion from 1950–1994 on the study sites. Juniper density and cover have consistently increased during this time period while precipitation has been more erratic (higher standard deviation), compared to the first half of the century. Because of their slow growth rates (Bedell et al. 1993), it is likely that many of the juniper observed in the 1951–1994 aerial photographs established during the early portion of the century, when conditions were (on average) drier at nearby Prineville (Table 1), or during the more favorable periods for establishment of the late 1800s shown on various western juniper chronologies for the surrounding region (Holmes et al. 1986) . We also note that patterns of establishment and expansion throughout central (e.g., Eddleman 1987) and southeastern Oregon (Miller and Rose 1995) have trended upward since the late 1800s under varying climatic conditions, and that density and cover values have accelerated from the 1950s.

Alternative causal mechanisms for western juniper expansion

Our results, showing increases in density and cover, are in basic agreement to what has been shown for the entire western juniper woodland range (e.g., Burkhardt and Tisdale 1976, Young and Evans 1981, Eddleman 1987, Miller and Wigand 1994, Miller and Rose 1995) . These studies have suggested that livestock grazing and/or altered fire regimes are likely the major causes for these shifts. Domestic livestock grazing and active fire suppression, along with climatic fluctuations, however, appear inadequate for explaining fully the changes observed on the Island Research Natural Area.

What then can explain the western juniper increases on the Island Research Natural Area? Despite a lack of organized fire suppression, there have not been any fires of significant areal influence since 1951 (and probably much longer) on the Island Research Natural Area. Thus, the current expansion on the Island Research Natural Area may simply be an artifact of the same fire-free period as that experienced on the more disturbed sites. We suggest that on near-relict sites such as the Island Research Natural Area, the rare combination of sufficient fine fuel accumulation and weather conditions necessary to promote and carry hot fires are infrequent enough to be only marginally consequential to inhibit juniper expansion.

Increases on all sites also may be a result of biological inertia (Miller and Rose 1995), which is partially manifested through increased seed rain. Western juniper typically reach full reproductive maturity at approximately 75 years of age (Bedell et al. 1993) . Thus, some of the increases in density and cover observed on the aerial photographs may be attributed to higher female cone production as many of the trees established decades ago during more favorable climatic conditions (e.g., late 1800s) reach reproductive maturity.

Our field reconnaissance of the study sites indicates that the majority of western juniper have prodigious berry production, and the ratio of juvenile (all awl-like foliage) to mature western juniper (all scale-like foliage) is large. While quantification of these observations was beyond the scope of this study, we can circumstantially infer that an increasing seed rain is a potential fac-

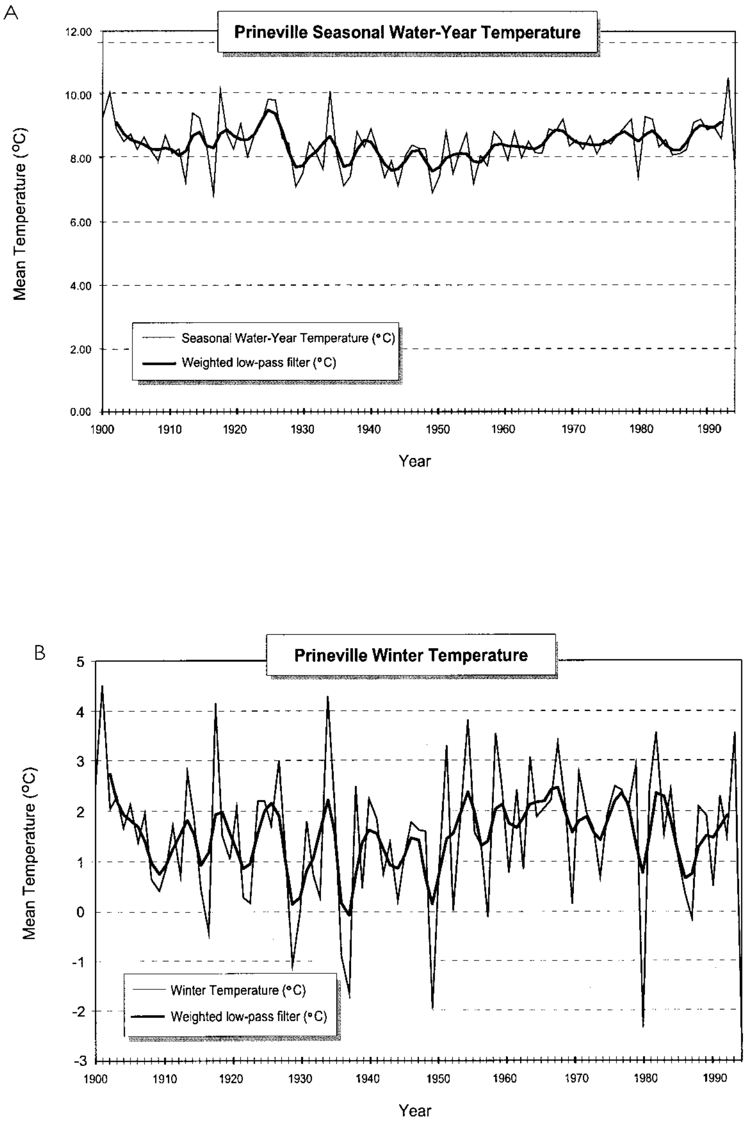

Fig. 8. Seasonal water-year temperature and winter temperature for Prineville, Ore.

tor in the observed density increases on the study sites from 1951–1994, and that, in the absence of a catastrophic fire, density will continue to increase as the juvenile population matures.

An additional possibility for western juniper expansion is increased seed dispersal (Archer 1994). That is, even in areas where domestic grazing has not occurred, and fire regimes have not been altered, an increase in cone production from nearby sites could result in expansion. In southwestern Idaho, Burkhardt and Tisdale (1976) found that western juniper seed dispersal primarily occurred downslope because of gravity and was spatially limited with an average maximum dispersal (during the summer) of 1.42 m. Dispersion by birds and mammals also was considered, but Burkhardt and Tisdale (1976) noted that the scarcity of disjunct western juniper stands in their study area suggested only a minor role for animal dispersion. Because the Island Research Natural Area is geographically isolated from the denser western juniper woodlands that surround it, seed dispersal would appear to play only a minimal role in the observed expansion.

It has been suggested that increasing levels of atmospheric CO_2 also may have influenced western juniper expansion (e.g., Miller and Wigand 1994, Knapp and Soulé 1998). In general, most species (particularly woody plants) may benefit from elevated CO_2 through increased photosynthesis, and/or reduced transpiration, thus increased water-use efficiency (Idso 1989, Idso and Kimball 1993). Juvenile western juniper appear physiologically well-suited to exploit atmospheric CO_2 (Miller et al. 1992, 1995). Miller et al. (1995:478) suggest that this physiologic advantage should both "enhance establishment and early growth," and increase the ability of juvenile western juniper to compete with other species. While tree growth exceeding that expected by climate in the later half of the twentieth century (when atmospheric CO_2 rates have increased most rapidly) has not (to our knowledge) yet been established for western juniper through dendroecological analyses, growth exceeding that expected by climate has been documented for some western coniferous species (e.g., LaMarche et al. 1984, Graybill and Idso 1993), opening the door for speculation that CO_2 enrichment is a possible contributing factor to western juniper expansion.

Conclusions

Western juniper expansion has profound management implications that must be addressed by the BLM and other governmental agencies (Evans 1988, Bedell et al. 1993, Haugen 1993, Liverman 1993) . This study shows that western juniper expansion can occur on lands with varied land use histories, on the arid end of its range, and on land that is not downslope from its founding population. Our results suggest that the mechanisms traditionally proffered to explain the post 1800s expansion of western juniper (i.e., domestic grazing, altered fire regimes, favorable climatic conditions) are not necessarily required to sustain expansion. Because the processes involved in western juniper afforestation are likely synergistic and site specific (Liverman 1993), the search for causal mechanisms should continue to include all potential elements that affect the dynamics of western juniper woodlands.

Literature Cited

Agee, J.K. 1993. Fire Ecology of Pacific Northwest forests. Island Press, Washington DC, USA.

Anderson, J.E. and K.E. Holte. 1981. Vegetation development over 25 years without grazing on sagebrush-dominated rangeland in southeastern Idaho. J. Range Manage. 34:25–29.

Archer, S. 1994. Woody plant encroachment into southwestern grasslands and savannas: Rates, patterns and proximate causes. Pages 13–68 *In:* M. Vavra, W.A. Laycock, and R.D. Pieper, editors. Ecological implications of livestock herbivory in the West. Society of Range Management, Denver, Colo.

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 University Extension Service, Corvallis, Ore.

Belsky, A.J. 1996. Viewpoint: Western juniper expansion: Is it a threat to arid northwestern ecosystems? J. Range Manage. 49:53–59.

Burkhardt, J.W. and E. W. Tisdale. 1969. Nature and successional status of western Juniper invasion in Idaho. J. Range Manage. 22:264–270.

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

Caraher, D.L. 1978. The spread of western juniper in central Oregon. *In:* R.E. Martin, J.E. Dealy, and D.L. Caraher (eds) . Proceedings of the western juniper ecology and management workshop. USDA Forest Serv. Gen. Tech. Rep. PNW-74. Portland, Ore. Pp. 1–7.

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

Eddleman, L.E. 1987. Establishment and stand development of western juniper in central Oregon. *In:* R.L. Everett, editor. Proceedings—Pinyon- Juniper Conference, USDA Gen. Tech. Rep. INT-215. Ogden, Ut. Pp. 255–259.

Evans, R.A. 1988. Management of Pinyon-Juniper Woodlands. Gen. Tech.Rep. INT-249. USDA, Ogden, Ut.

Franklin, J.F. and C.T. Dyrness. 1988. Natural Vegetation of Oregon and Washington. Oregon State University Press, Corvallis, Ore.

Gifford, G. F. 1987. Myths and Fables and the Pinyon-Juniper type. *In:* Proceedings—Pinyon-Juniper Conference (ed. R. L. Everett), pp. 34-37. Gen. Tech. Rep.INT-215. USDA, Ogden, Ut.

Goldberg, D.E. and R.M. Turner. 1986. Vegetation change and plant demography in permanent plots in the Sonoran Desert. Ecol. 67:695-712.

Graybill, D. A. and S. B. Idso. 1993. Detecting the aerial fertilization effect of atmospheric CO_2 enrichment in tree-ring chronologies. Global Biogeochemical Cyc. 7:81–95.

Haugen, J. 1993. Proceedings of the Western Juniper Forum. USDA Forest Serv., Winema National Forest, Klamath Falls, Ore.

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. Chronology Series VI, Lab. of Tree-Ring Res., Univ.. of Arizona, Tucson, Ariz.

Hopkins, W.E. and B.L. Kovalchik. 1983. Plant Associations of the Crooked River National Grassland. USDA For. Serv. PNW-R6-Ecol-133. Portland, Ore.

Idso, S.B. 1989. Carbon Dioxide and Global Change: Earth in Transition. Tempe: IBR Press.

Idso, S.B. and R.C. Balling, Jr. 1992. United States drought trends of the past century. Ag. For. Meteor. 60:279–284.

Idso, S.B. and B.A. Kimball. 1993. Tree growth in carbon dioxide enriched air and its implications for global carbon cycling and maximum levels of atmospheric CO_2. Global Biogeochemical Cycles 7:537–555.

Karl, T.R. and R.R. Heim, Jr. 1990. Are droughts becoming more frequent or severe in the United States? Geophys. Res. Letters. 17:1921–1924.

Karl, T.R., C.N. Williams Jr., F.T. Quinlan, and T.A. Boden. 1990. United States Historical Climatology Network (HCN) Serial Temperature and Precipitation Data. Oak Ridge, Tennessee, Carbon Dioxide Information Analysis Center.

Knapp, P.A., and P.T. Soulé. 1996. Vegetation change and the role of atmospheric CO_2 enrichment on a relict site in central Oregon: 1960–1994. Annals Assoc. Amer. Geog. 86(3):387–411.

Knapp, P.A. and P.T. Soulé. 1998. Recent *Juniperus occidentalis* (Western Juniper) Expansion on a Protected Site in Central Oregon. Global Change Bio. 4:347–357.

Knapp, P. A., P.L. Warren, and C.F. Hutchinson. 1990. The use of large-scale aerial photography to inventory and monitor arid rangeland vegetation. J. Environ. Manage. 31:29–38.

LaMarche, V. C., D. A. Graybill, H. C. Fritts, and H. R. Rose. 1984. Increasing atmospheric carbon dioxide: tree-ring evidence for growth enhancement in natural vegetation. Sci. 225:1019–1021.

Liverman, H. 1993. Application of the Habitat Mitigation Policy to Juniper Woodland Management. Internal Technical Guidance Document for Management of Western Juniper. Oregon Dept. of Fish and Wildl., Habitat Conser. Div., Portland, Ore.

Miller, P.M, L.E. Eddleman, and J.M. Miller. 1992. The seasonal course of physiological processes in *Juniperus occidentalis*. Forest Ecol. Manage. 48:185–215.

Miller, P.M., L.E. Eddleman, and J.M. Miller. 1995. *Juniperus occidentalis* juvenile foliage: advantages and disadvantages for a stress-tolerant, invasive conifer. Canadian J. of Forest Res. 25:470–479.

Miller, R.F. and P.E. Wigand. 1994. Holocene changes in semiarid pinyon-juniper woodlands. BioSci. 44:465–474.

Miller, R.F. and J.A. Rose. 1995. Historic expansion of *Juniperus occidentalis* (western juniper) in southeastern Oregon. Great Basin Nat. 55:37–45.

Miller, R.F., R.F. Angell, and L.E. Eddleman. 1987. Water use by western juniper. pp. 418–422 *In:* R.L. Everett, editor. Proceedings—Pinyon-juniper conference Gen. Tech. Rep. INT-215. USDA Forest Serv., Ogden, Ut.

Miller, R.F., T.J. Svejcar, and N.E. West. 1994. Implications of livestock grazing in the intermountain sagebrush region: Plant composition. pp. 101–146 *In:* M. Vavra, W.A. Laycock, and R.D. Pieper, editors. Ecological implications of livestock herbivory in the West. Society of Range Management, Denver, Colo.

Plantico, M.S., T.R. Karl, G. Kukla, and J. Gavin. 1990. Is recent climate change across the United States related to rising levels of anthropogenic greenhouse gases? J. Geophys. Res. 95:16617–16637.

Poulton, C.E. (ed.) 1975. Range resources: Inventory, evaluation, and monitoring. *In:* Manual of Remote Sensing. American Society of Photogrammetry. Falls Church, Virg. Pp.1427–1474.

Soulé, P.T. and Z-Y Yin. 1995. Short- to long-term trends in hydrologic drought conditions in the contiguous United States. Clim. Res. 5:149–157.

USDA—Natural Resources Conservation Service. In press. Upper Deschutes River Area, Oregon Soil Survey. USDA-NRCS, Washington, DC.

Vaitkus, M.R. and L.E. Eddleman. 1991. Tree size and understory phytomass production in a western juniper woodland. Great Basin Nat. 51:236–243.

Yin, Z-Y. 1993. Spatial pattern of temporal trends in moisture conditions in the southeastern United States. Geografiska Annaler, Ser. A 75:1–11.

Young, J.A. and R.A. Evans. 1981. Demography and fire history of a western juniper stand. J. Range Manage. 34:501–506.