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ABSTRACT

*Western juniper (*Juniperus occidentalis*) woodlands in Oregon have expanded four-fold from 600,000 ha in 1930 to > 2.6 million ha, often resulting in the reduction and fragmentation of sagebrush (*Artemisia spp.*) communities. We documented dynamics of western juniper across the John Day Ecological Province in central Oregon by recording size class and growth form at 178 sites. We used stratified random sampling, with strata based on vegetation association (sagebrush, juniper, other) and distance from juniper stands. Only 26 percent of sites contained pre-settlement trees (in other words, > 140 years old), and < 5 percent of the 2,254 junipers tallied were pre-settlement trees. Mean densities of pre-settlement trees by stratum ranged from 0 to 18 trees/ha, suggesting that historically, juniper was widely scattered across the landscape. Current densities of post-settlement trees ranged from 75 to 211 trees/ha in non-woodland strata to 457 trees/ha in the juniper stratum. Juniper in non-woodland strata was most abundant in sites adjacent to juniper stands and in sagebrush communities. Mean densities of post-settlement trees were greatest in the > 2.0-m tall size class (82 trees/ha), followed by the 0.3 to 1-m tall size class (52 trees/ha). These densities pose substantial risk to sagebrush communities in central Oregon. Questions remain about the extent of western juniper woodlands across the species' range that have replaced or are expanding into sagebrush communities versus sites that historically supported woodlands. However, our findings suggest that within sagebrush communities of the John Day province, intensive management through removal of western juniper may be prudent, while retaining pre-settlement trees.*

INTRODUCTION

A striking change in landscapes of the western United States during the past 100 to 150 years has been the expansion of pinyon-juniper (*Pinus* L. – *Juniperus* L.) woodlands into the sagebrush (*Artemisia* spp.) ecosystem (Chambers 2001; Miller and Rose 1995; Miller and Tausch 2001; Miller and others 1999a; figure 1) and, to a lesser extent, grassland ecosystems (Coppedge and others 2004; Miller and others 2005; Taylor 2007). Pinyon-juniper woodlands have increased 10-fold in extent throughout the Intermountain West since the late 1800s and currently encompass at least 30 million ha (Miller and Tausch 2001). These woodlands are likely to continue to expand because conditions under which these communities thrive include currently unoccupied areas (Betancourt 1987; West and Van Pelt 1987). Pinyon and juniper species can be successionally aggressive across their range and, once they invade, can eliminate the understory component of a community (Azuma and others 2005; Johnsen 1962; Miller and others 2000; Tausch and Tueller 1990).

Figure 1–Encroaching western juniper in a big sagebrush community near Mitchell, Oregon.

Existing pinyon-juniper woodlands have been shaped by long-term interactions between environmental conditions, including climate and current vegetation (Miller and Wigand 1994; Tausch 1999). Several events during the last 150 years led to increased rates of woodland establishment throughout the Intermountain West. These include: climate change, with rising temperatures; intensive livestock use; decreased wildfire and increased fire suppression; and increasing atmospheric CO2 that benefited the dominance of large, woody perennial plants (Brown and Smith 2000; Clark and others 1998; Gedney and others 1999; Miller and others 2005; 2008; Miller and Rose 1995; Soulé and others 2003; Tausch 1999). The risk of crown fire in these increasingly dense woodlands is perhaps greater than at any time since the Neoglacial period (Miller and others 2008; Tausch 1999).

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Once established, woodlands may provide wood products (Pieper and others 2002) and habitat for many wildlife species (for example, Belsky 1996; Dobkin and Sauder 2004; Miller and others 2005; Pavlacky and Anderson 2001; Rumble and Gobeille 1995), and potentially serve as carbon sinks (Hubbard and others 2003). However, conversion of sagebrush and other native plant communities to pinyon-juniper woodlands places additional stress on communities that have been severely reduced in area and habitat quality (Connelly and others 2004; Miller and others 1999a, Schaefer and others 2003). These landcover conversions may have profound ecological implications (Huxman and others 2005).

Concurrent with and partially due to woodland expansion, the sagebrush ecosystem in western North America has dramatically declined in quality and quantity (Bunting and others 2002; Knick 1999; Miller and Eddleman 2000; Wisdom and others 2005). Sagebrush-associated fauna, such as greater sage-grouse (*Centrocercus urophasianus*), pygmy rabbit (*Brachylagus idahoensis*), and Brewer's sparrow (*Spizella breweri*), are considered species of concern across much of their range (Connelly and others 2004; Dobkin and Sauder 2004; Knick and others 2003; Rowland and others 2005). Moreover, the threat of woodland encroachment was determined to be an extinction risk for greater sage-grouse in the western portion of its range (USDI Fish and Wildlife Service 2005). Connelly and others (2004) also identified pinyon-juniper woodland encroachment as a threat in their range-wide conservation assessment of greater sage-grouse habitats. However, old-growth pinyon-juniper, which should be distinguished from expansion woodlands, provides essential habitat for many woodland-associated species of conservation concern (Miller and others 1999b, Reinkensmeyer and others 2008).

In addition to displacing plant communities such as sagebrush and being implicated in the increasing distribution of invasive plants such as cheatgrass (*Bromus tectorum*),1 encroaching woodlands also increase fuel loads, thereby leading to changes in fire regimes (Chambers and others 2005). Pinyon and juniper species are highly flammable and vulnerable to fire (Brown and Smith 2000). The issue of pinyon-juniper expansion is particularly problematic because the phenomenon is geographically widespread and is a potentially divisive issue among public land users (for example, Nelson and others 1999). Woodland expansion is also considered a threat to effective management of forage resources for livestock (Bates and others 2000; Gholz 1980). In Oregon, pinyon-juniper woodlands comprise a single species, western juniper (*Juniperus occidentalis*) (hereafter referred to as juniper). This species represents the northwestern extension of pinyon-juniper woodlands in the Intermountain West (Miller and others 2005). Juniper woodlands have expanded four-fold in Oregon since 1930, from 600,000 ha to more than 2.6 million ha (Azuma and others 2005). Juniper grows on xeric lands in Oregon, generally at elevations between 900 and 1,500 m and in locations with 25 to 50 cm annual precipitation (Azuma and others 2005; Gedney and others 1999). In Oregon, juniper is typically classified as either juniper forest (> 10 percent crown cover of juniper) or savanna (juniper present but < 10 percent crown cover and < 5 percent stocking) (Azuma and others 2005; Gedney and others 1999). As of 1999, Oregon had an estimated 1.35 million ha of juniper forest and 1.31 million ha of juniper savanna. The extent of juniper forest in Oregon is predicted to increase as small junipers grow and juniper savannas convert to forests (Azuma and others 2005).

Our primary objective in this paper is to describe the dynamics of juniper establishment in existing sagebrush communities of central Oregon, specifically by describing densities, age, and height classes of juniper measured in sagebrush-dominated sites. A second objective is to describe the structure of existing juniper stands in central Oregon. The results described below are part of a comprehensive, ongoing project to evaluate a model to estimate risk of woodland encroachment into sagebrush with field and remotely sensed data (Suring and others 2005). By understanding the current and predicted extent of juniper encroachment into sagebrush, managers can assume a balanced approach to woodland management that maintains old-growth juniper while engaging in active restoration of sagebrush communities where prudent and feasible.

METHODS

Study Site

Eastern Oregon

The climate of eastern Oregon, from the crest of the Cascade Mountains eastward, is highly variable because of maritime, continental, and arctic influences (Ferguson 2001). Temporal and spatial variability in climate is evident at watershed scales throughout eastern Oregon due to complex topography and mosaics of land cover (Mock 1996). Median annual minimum temperatures for eastern Oregon vary from -18° C in the more protected areas of the Columbia Basin to -32° C in the high mountains and plateaus. July mean temperatures range between 18° C and 21° C in the central valleys and plateaus and up to 26° C along the eastern border with Idaho. Precipitation is generally low, ranging from 10 to 50 cm annually (Campbell and others 2003).

Thirty-five percent (> 6 million ha) of eastern Oregon is forested (in other words, ≥ 10 percent forest cover); the remainder supports grasses and shrubs (Campbell and others 2003). Several tree species are abundant at higher elevations (> 1200 m) including ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), grand

fir (*Abies grandis*), and quaking aspen (*Populus tremuloides*) (Franklin and Dyrness 1973). At lower elevations (760 to 1400 m), western juniper savannas occur in a zone between ponderosa pine forests and shrub and grass communities. Within the shrub communities dominant species include big sagebrush (*Artemisia tridentata*), antelope bitterbrush (*Purshia tridentata*), scabland sagebrush (*A. rigida*), low sagebrush[1] (*A. arbuscula*), and shadscale saltbush (*Atriplex confertifolia*). Within the grassland communities dominant species include bluebunch wheatgrass (*Pseudoroegneria spicata*), Idaho fescue (*Festuca idahoensis*), basin wildrye (*Elymus cinereus*), Thurber's needlegrass (*Stipa thurberiana*), and the invasive annual grass cheatgrass.

John Day Ecological Province[2]

We used the ecological provinces from Miller and others (1999a) and West and others (1998) as the geographic basis for development of rules for the woodland model and associated data collection and analysis. Ecological provinces are large areas (in other words, millions of ha), each of which is defined by similarity in regional climate, topography, potential natural communities, geology, and soils (Anderson and others 1998; Suring and others 2005; West and others 1998). The ecological characterization of landscape conditions within each of the provinces provided a useful and important ecological context for describing juniper relationships with environmental factors (for example, Miller and others 2008).

We selected the John Day province for our analysis because of its diversity of sagebrush communities and the widespread distribution of western juniper (figure 2). The John Day province extends across much of east-central Oregon, encompassing 3.5 million ha with diverse land covers ranging from coniferous forests to expansive shrub and grass communities. The province is topographically diverse with valleys and dissected hills interspersed with taller buttes and plateaus. Watersheds of the Crooked River and John Day River (with the exception of the Upper North Fork) are contained within the John Day province. Elevation ranges from 335 to 3,060 m ($\bar{x}$ = 1,262 m), with the highest elevations in the Ochoco Mountains. Average annual precipitation across the province is 48 cm. Over half of the rainfall occurs between November and March. Soils in the province are primarily fine-textured and calcareous.

[1]Plant nomenclature follows USDA Natural Resources Conservation Service (2008). One exception is our use of the common name "low sagebrush" for *Artemisia arbuscula*, instead of the recommended name "little sagebrush."

[2]See Anderson and others (1998) for a more in-depth description of the John Day province and for descriptions of other ecological provinces in Oregon.

The LANDFIRE existing vegetation type (EVT) map is one of a suite of nationwide grids developed to provide consistent mapping of ecosystems, fuels, and fire across the U.S., with a 30-m (0.09 ha) resolution (Rollins and Frame 2006). We selected LANDFIRE to describe current land cover for our analysis due to its national coverage and consistency. Ninety-two "ecological systems" (a mid-scale vegetation classification system, between fine-grained ecological communities and coarse-grained ecoregions; see Comer and others [2003]) occur in the province, as mapped by LANDFIRE. Most (76), however, each comprise < 1 percent of the study area. Coniferous forests dominate the vegetation, with ponderosa pine and mixed dry conifer forests together covering nearly 30 percent of the province.

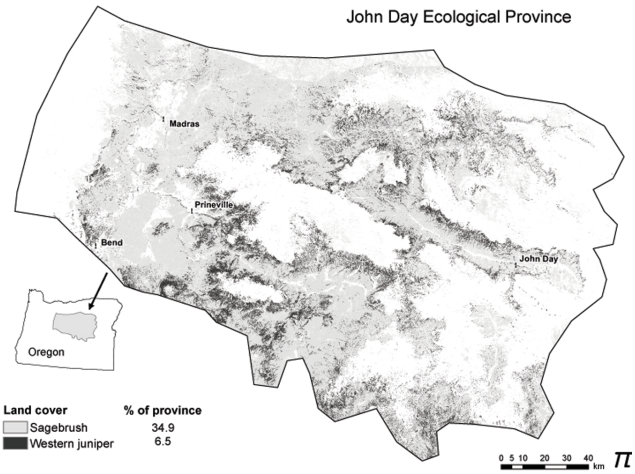

Figure 2–Western juniper and sagebrush (all sagebrush ecological systems combined) as mapped by LANDFIRE in the John Day Ecological Province, central Oregon. See text for details.

The most abundant (550,000 ha; 15.6 percent) single vegetation type is Inter-mountain Basins Big Sagebrush Steppe, which is a widespread, matrix-forming system (in other words, a patch type forming extensive and continuous cover; [Comer and others 2003]) composed primarily of Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) and basin big sagebrush (*A. t. tridentata*). Other common sagebrush types in the John Day province include mountain big sagebrush (*A. t. vaseyana*), low sagebrush, and scabland sagebrush. All sagebrush types combined cover 1.23 million ha (34.9 percent) of the province (figure 2). The majority of sagebrush is on private lands (60.7 percent), which is somewhat higher than expected given the extent of private lands in the province (47.2 percent; figure 3). The same is true for the percentage of sagebrush managed by the USDI Bureau of Land Management (BLM) (21.2 percent) compared to the extent of BLM-administered lands in the province (13.0 percent). The USDA Forest Service manages only 8 percent of the sagebrush (16,180 ha; much of this is mountain big sagebrush) but manages 32.8 percent of the John Day province.

The area is mostly rural, with human populations centered at Bend, John Day, Madras, and Prineville. Livestock production, agriculture, extraction of minerals, and timber harvest on private and public lands provide the basis for local economies and, as a result, strongly influence the social structure of the study area.

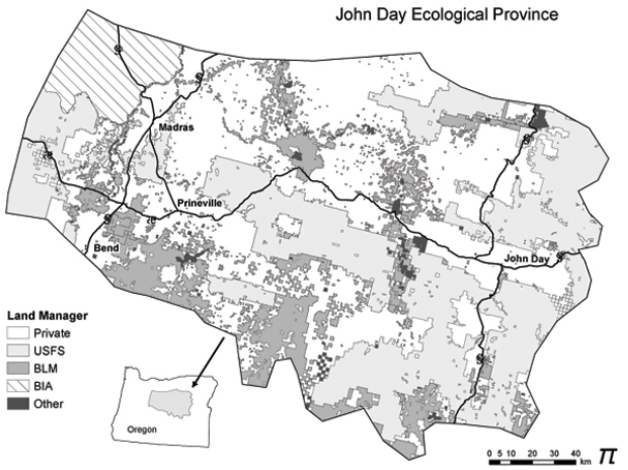

Figure 3–Location of the John Day Ecological Province in central Oregon. Land managers are as follows: USFS = USDA Forest Service, BLM = USDI Bureau of Land Management, BIA = USDI Bureau of Indian Affairs, and Other, including Oregon Department of State Lands and USDI Fish and Wildlife Service.

Sampling Design

Sample Stratification

The target frame for field sampling was any pixel of a sagebrush land cover type (as delineated by the 30-m pixels in the LANDFIRE EVT map; figure 2) within the John Day province. The sampling frame was considerably smaller, however, due to logistical constraints associated with collection of field data (for example, plots were located < 1 km of a road to decrease travel time to plots). To ensure that a representative sample was obtained from a range of environmental conditions, we used a stratified random approach. Due to the limited number of plots that we estimated could be sampled during the field season (~200), we formed six sampling strata representing combinations of two key variables—land cover type (3 classes) and proximity to juniper stands[3] (2 classes) (table 1). We added a 7th stratum, juniper stands, to obtain estimates of tree density and size distribution in sites mapped as existing western juniper by LANDFIRE, for comparison with juniper conditions in sagebrush sites at various stages of juniper encroachment.

Non-woodland (in other words, all but juniper) ecological systems were collapsed into three types for the stratification: mountain big sagebrush/low sagebrush, other sagebrush, and non-sagebrush (table 1). We stratified by mountain big sagebrush, despite its rarity (1.8 percent, estimated using LANDFIRE) in the province, because it is a key sagebrush type, especially as brood-rearing habitat for greater sage-grouse, and is typically the dominant sagebrush taxon on National Forest System lands. Also, a review of BLM sagebrush plot data (~1200 records for the province) within sites mapped as western juniper revealed that most of the records reported mountain big sagebrush as the dominant shrub. Thus, this type may be important in the sagebrush/juniper ecotone in our study area.

We used two buffer zones extending out from juniper stands (1 – 1600 m and 1600 – 5000 m) to create strata delineating proximity to juniper stands and thereby describe dynamics of juniper encroachment (table 1). Juniper seeds are commonly dispersed ≤ 1.6 km from juniper stands by birds and mammals (Schupp and others 1999). Birds have also been reported to disperse seeds up to 5 km from seed sources, but in lesser amounts (Vander Wall and Balda 1977, 1981).

We delineated these seven strata across the John Day province with a geographic information system (GIS) (table 1). We then applied a series of filters to remove non-targeted or inaccessible areas from the sampling frame as follows:

1. Private or tribal lands (to facilitate access);
2. Areas < 100 m of an accessible (in other words, non-private) road (to ensure that no portion of the sample plot fell within ~50 m of a road and associated disturbance effects);
3. Areas > 1.0 km from accessible roads (to reduce travel time to plots);
4. The Crooked River National Grassland (because of extensive, long-term land management actions, such as juniper removal and seeding projects); and
5. Areas that were not homogeneous in terms of stratum type; if < 6 pixels out of 9 in a 3 x 3 neighborhood were classified the same as the center pixel, the pixel was removed from the sampling pool.

Within the area remaining after the above filters were applied, 75 random points were generated in each of the seven strata using a GIS. If a random point was assigned to a pixel within 200 m of a previously generated point, the point was dropped and a new point generated in the GIS. This step eliminated sampling of points that were too close together to represent independent samples of woodland condition, which we characterized at a scale of ~1 ha with our sampling design. The resulting spatial distribution of sample points was examined to ensure that an adequate geographic representation of sagebrush across the province was captured.

[3]A "stand" of juniper was defined as ≥ 10 ha of contiguous juniper pixels for this analysis.

The targeted number of plots to sample within each of the strata was determined by a weighting factor that incorporated both the proportion of available pixels in the stratum and the estimated variance of juniper densities within that stratum (table 1). For example, 71 of the estimated 200 plots to be sampled were allocated to the stratum containing "other sagebrush, far from juniper stands," due to the complex of sagebrush taxa that could occur in the "other sagebrush" type as well as the higher uncertainty about juniper densities with increasing distance from juniper stands. We also pre-screened plots in the two non-sagebrush strata using digital aerial photography to eliminate sampling plots in dense conifer stands, which were not pertinent for this analysis.

During the field season we periodically compared the number of plots sampled per stratum against the desired number of samples per stratum to ensure that sampled plots represented the correct balance of plots among strata.

Field Methods

We adapted rangeland sampling methods from Herrick and others (2005) for data collection in the John Day province in 2007. Locations of plot centers in a global positioning system (GPS) were pre-assigned from the sample point allocation process described above. A plot (and sample unit) consisted of three 50-m transects radiating from a center stake. The three transects were arranged in a spoke design, with meter tapes laid out at azimuths of 0, 120, and 240 degrees from the plot center. The total area represented by each plot was thus ~0.8 ha. Line-intercept sampling was used along the three transects to assess canopy cover of trees and shrubs. The total length of canopy (in cm) intersecting the transect was recorded for each species. Intercept measures for dead trees and shrubs were also recorded, due to their importance in indicating current ecological function.

Tree density and size class were measured at each site using a modified Forest Inventory and Analysis plot design (USDA Forest Service 2007). Trees were measured in four circular, 7.3-m radius subplots. One subplot was located at the plot center; the other three were located at points 36.6 m from the plot center along each of the three transect lines.

Within each subplot, all trees were tallied by species. Junipers were assigned to one of four height classes: < 0.3 m, 0.3 – 1 m, 1 – 2 m, and > 2 m; and to one of two growth forms for trees > 2 m tall (representing trees from pre- or post-European settlement; pre-settlement trees are > 140 years old) (Gascho Landis and Bailey 2006; Miller and others 2005).

Table 1—Allocation of sampling points across sampling strata.

Stratum Number	Stratum Description[a]	Percent of Target Frame	Percent of Sampling Frame[b]	Projected Number of Sample Plots[c]	Actual Number of Plots Sampled
1	Non-sagebrush, far from juniper stands	46	68	7	4
2	Other sagebrush, far from juniper stands	15	9	71	51
3	Low/mountain big sagebrush, far from juniper stands	5	2	21	21
4	Non-sagebrush, near juniper stands	16	13	7	10
5	Other sagebrush, near juniper stands	10	4	57	54
6	Low/mountain big sagebrush, near juniper stands	6	3	29	26
7	Juniper stands	4	1	7	12
	Total	**100**	**100**	**200**	**178**

[a]Far from juniper stands = 1,600 – 5,000 m; near juniper stands = < 1,600 m.
[b]Following application of filters to remove non-targeted or inaccessible areas.
[c]Following application of weighting factors that incorporated the proportion of available pixels in a stratum and the estimated variance of juniper densities within that stratum.

RESULTS

We sampled trees and shrubs on 178 plots throughout the John Day province (table 1). Juniper trees were recorded on 150 (84 percent) of the sample plots; plots without juniper were found in all strata except 1 and 7 (table 2). Among the 2,254 trees counted, 2,225 (98.7 percent) were live. Dead western junipers were recorded in only 17 (9.6 percent) plots, and nearly all were in the "other sagebrush" strata (in other words, 2 and 5). Mean density of dead junipers across all plots and size/age classes was 2.4 trees/ha, compared to 186.7 trees/ha for live trees. Within the 17 plots with dead trees, most dead junipers were large (> 2 m), pre-settlement trees (mean density = 16.7 trees/ha); only 3 post-settlement dead junipers were recorded in the > 2 m size class.

We encountered pre-settlement trees in only 47 (26 percent) plots (table 2), and < 5 percent of the total junipers tallied were pre-settlement trees. The largest number and percentage of plots with pre-settlement juniper were in other sagebrush, far from juniper (stratum 2).

Juniper Density

Mean densities of pre-settlement trees ranged from 0 in stratum 3 to 17.6 trees/ha in stratum 2 (table 3). Notably, density of old trees in plots mapped as juniper (in other words, stratum 7) was only moderate (6.2 trees/ha). A high proportion of plots in all strata contained post-settlement junipers, with the exception of stratum 3 (table 2). Mean densities of post-settlement trees ranged from 74.7 to 211.3 trees/ha in non-woodland strata (in other words, plots within strata 1 to 6; n = 166) to 456.7 trees/ha in juniper plots (n = 12) (table 3). Juniper in non-woodland plots was most abundant in sites adjacent to juniper stands (in other words, plots within strata 4 to 6) vs. the equivalent strata far from juniper (in other words, strata 1 to 3), and in "other sagebrush" communities (in other words, plots within strata 2 and 5) compared to low/mountain big sagebrush (in other words, strata 3 and 6).

Densities of post-settlement trees were greatest in the > 2.0-m size class (mean = 82.0 trees/ha), followed by the 0.3–1 m size class (mean = 51.7 trees/ha) (table 4). Mean density in the smallest size class (< 0.3 m tall) was 21.4 trees/ha. Comparing within strata, juniper densities were greatest in the > 2 m-tall size class for all strata except the two low/mountain big sagebrush strata (3 and 6), for which densities were greatest in the 0.3 – 1 m class.

Canopy Cover

Canopy cover of juniper, as estimated with line intercept, ranged from 0 (n = 47 plots; all strata except 7) to 36.4 percent within a juniper plot. Canopy cover of juniper trees was highest in stratum 7, as expected (figure 4). Outside this stratum (in other words, in sagebrush and other vegetation communities) juniper canopy cover was lowest in strata 3 and 6 (low/mountain big sagebrush), and highest in stratum 5, near existing juniper stands. Sagebrush canopy cover was greatest in the two low/mountain big sagebrush strata, and lowest in the two non-sagebrush strata (1, and 4) and in juniper stands (figure 4). Canopy cover of all sagebrush taxa combined was negatively correlated with canopy cover of juniper in our plots (r = -0.45; figure 5).

DISCUSSION

Dynamics of juniper woodlands in the John Day province paralleled those recorded in several other studies conducted across the western United States (for example, Gedney and others 1999; Miller and others 2005, 2008), and suggest widespread encroachment of western juniper into sagebrush and other shrublands of central Oregon. Two of our sampling strata had juniper present on all plots, including juniper stands themselves and stratum 1 (non-sagebrush, far from juniper). We sampled only four plots in this stratum, and all were in mixed conifer forests, except for one juniper-encroached scabland sagebrush site.

We encountered few dead junipers, most of which were pre-settlement trees. The mean density of dead pre-settlement trees (in plots with dead trees present) was 16.8 trees/ha, similar to that reported for standing dead trees in old-growth juniper stands on aeolian soils of the High Desert province (up to 14.8 trees/ha; Miller and others 2005).

Six ecological provinces of the Intermountain West, including the John Day, support pre-settlement western juniper (Miller and others 1999b). Old junipers in the sedimentary soils of the John Day province have not been well-studied, but are typically widely spaced, resulting in very low densities with insufficient understory fuels to carry a fire (Miller and others 1999b). The low density of pre-settlement junipers that we recorded in juniper plots (6.7 trees/ha) confirms this pattern.

We found low percentages of mixed-age (in other words, co-occurrence of both pre- and post-settlement trees) plots and of old trees (compared to total trees) in the John Day province, suggesting that historically, junipers were widely scattered across the landscape. Our findings are similar to those reported in pinyon-juniper woodlands within four other ecological provinces in the Intermountain West (Miller and others 2008). The percentage of mixed-age plots in that study ranged from 16 percent to 30 percent in Nevada, Oregon, and Utah. Similar to our results, the percentage of old juniper trees, relative to total junipers, ranged from ¬< 2 percent in Nevada, Oregon, and Utah sites to 10 percent in Idaho sites. A study of western juniper woodlands in four sites in Oregon and Idaho also reported low percentages (1 to 10 percent) of pre-settlement trees, and 17 percent of the juniper stands in Oregon were mixed age (Johnson and Miller 2008). The density of pre-settlement junipers we recorded was somewhat lower than that found by Miller and others (2008), who reported pre-settlement tree densities of 20 and 27 trees/ha in their Idaho sites, where old trees were most abundant.

Table 2—Presence of western juniper trees in plots sampled in the John Day province, central Oregon, 2007 (n = 178); data refer to live trees only. See text for definitions of pre- and post-settlement trees.

Stratum Number	Stratum Description[a]	No. Plots (% of total)	Plots with Pre-settlement Juniper (% of stratum)	Plots with Post-settlement Juniper (% of stratum)	Plots with Juniper Absent (% of stratum)
1	Non-sagebrush, far from juniper stands	4 (2.3)	1 (25.0)	4 (100)	0 (0.0)
2	Other sagebrush, far from juniper stands	51 (28.7)	25 (49.0)	46 (90.0)	5 (10.0)
3	Low/mountain big sagebrush, far from juniper stands	21 (11.8)	0 (0.0)	10 (47.6)	11 (52.3)
4	Non-sagebrush, near juniper stands	10 (5.6)	2 (20.0)	8 (80.0)	1 (10.0)
5	Other sagebrush, near juniper stands	54 (30.3)	14 (25.9)	48 (88.9)	6 (11.1)
6	Low/mountain big sagebrush, near juniper stands	26 (14.6)	3 (11.5)	21 (80.8)	5 (19.2)
7	Juniper stands	12 (6.7)	2 (16.7)	12 (100)	0 (0.0)
	Total	**178 (100)**	**47 (26.4)**	**149 (83.7)**	**28 (15.7)**

[a]Far from juniper stands = 1,600 – 5,000 m; near juniper stands = < 1,600 m.

Table 3—Mean density (number of trees/ha) and 90percent confidence interval (CI) for western juniper in plots sampled in the John Day province, central Oregon, 2007 (n = 178); data refer to live trees only. See text for definitions of pre- and post-settlement trees.

Stratum Number	Stratum Description[a]	All Juniper		Post-settlement Juniper		Pre-settlement Juniper	
		Mean	CI	Mean	CI	Mean	CI
1	Non-sagebrush, far from juniper stands	119.5	125.6	104.5	131.1	14.9	24.6
2	Other sagebrush, far from juniper stands	177.1	38.9	159.6	39.1	17.6	5.4
3	Low/mountain big sagebrush, far from juniper stands	74.7	63.8	74.7	63.8	0.0	NA
4	Non-sagebrush, near juniper stands	167.2	90.3	164.3	89.2	3.0	3.3
5	Other sagebrush, near juniper stands	220.4	41.0	211.3	40.1	9.1	5.0
6	Low/mountain big sagebrush, near juniper stands	116.0	66.8	113.7	66.1	2.3	2.2
7	Juniper stands	462.9	152.0	456.7	155.5	6.2	8.3

Table 4—Mean density (number of trees/ha) of post-settlement western juniper trees by height class in plots sampled in the John Day province, central Oregon, 2007 (n = 178). Data refer to live trees only; post-settlement trees are < 140 years old.

Stratum Number	Stratum Description[a]	< 0.3 m	0.3–1 m	1–2 m	> 2 m
1	Non-sagebrush, far from juniper stands	26.1	22.4	11.2	44.8
2	Other sagebrush, far from juniper stands	19.3	43.6	22.3	74.4
3	Low/mountain big sagebrush, far from juniper stands	8.5	39.1	10.7	16.4
4	Non-sagebrush, near juniper stands	29.9	38.8	13.4	82.1
5	Other sagebrush, near juniper stands	22.1	60.8	23.8	104.5
6	Low/mountain big sagebrush, near juniper stands	19.0	40.2	18.4	36.2
7	Juniper stands	46.0	112.0	58.5	240.2

Post-settlement junipers were far more abundant than old junipers in our sample plots. At least 80 percent of the plots in all strata except stratum 3 had post-settlement trees present. The density of post-settlement trees in juniper (in other words, stratum 7) plots (456.7 trees/ha) was comparable to that reported by Miller and others (2008) for pinyon-juniper woodlands of the Intermountain West, which ranged from 197 trees/ha in Idaho to 885 trees/ha in Utah. The majority of juniper forest in Oregon occurs in stands with < 123 trees/ha (Gedney and others 1999). Juniper densities exceeded this value in nearly 50 percent of our plots, most of which were classified by LANDFIRE not as juniper, but as sagebrush. Densities of juniper seedlings as low as 62/ha are considered indicative of continued woodland expansion (Azuma and others 2005); about one-third (n = 47) of the sagebrush plots we sampled, and 60 (33.7 percent) plots altogether, had densities of small (0 to 1 m tall) junipers exceeding this value.

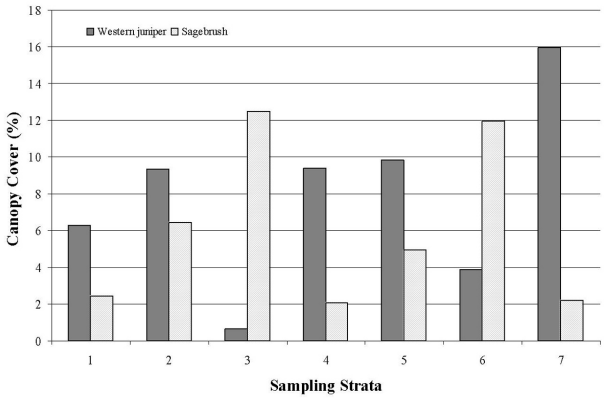

Figure 4–Canopy cover (percent) of western juniper trees and sagebrush in plots sampled in the John Day province, central Oregon, 2007 (n = 178). Strata are defined as follows: 1 = non-sagebrush, far from juniper stands, 2 = other sagebrush, far from juniper stands, 3 = low/mountain big sagebrush, far from juniper stands, 4 = non-sagebrush, near juniper stands, 5 = other sagebrush, near juniper stands, 6 = low/mountain big sagebrush, near juniper stands, and 7 = juniper stands. Far from juniper stands = 1,600 to 5,000 m; near juniper stands = < 1,600 m.

Comparison of densities of post-settlement junipers across size classes revealed that the dominant size class was > 2 m. However, junipers in the 0.3 to 1 m class were also abundant, suggesting continued establishment and encroachment of junipers in the John Day province. The juniper densities and associated sagebrush canopy cover we measured suggest active expansion of western juniper into shrublands of the John Day province, characterized as Phase I or II woodlands.[4]

Further exacerbating predicted juniper expansion in central Oregon are effects of increasing atmospheric CO2 levels. Knapp and others (2001), by using matched sets of drought and wet years pre- and post-1950, demonstrated consistently more rapid growth rates of western juniper in central Oregon in recent decades, presumably a fertilization effect of CO2 that increases water use efficiency of juniper. The precise relation of increasing CO2 levels and western juniper expansion is not well understood, however (Miller and others 2005; Soulé and Knapp 1999).

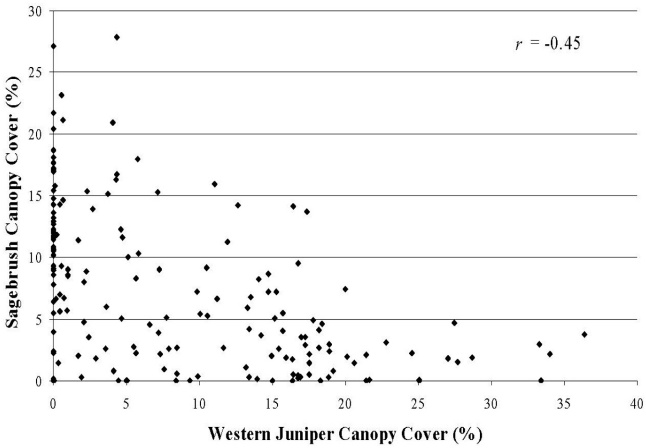

Figure 5–Canopy cover of western juniper trees and sagebrush (all taxa combined) on plots within seven strata sampled in the John Day province, central Oregon, 2007 (n = 178). (See table 1 for strata descriptions).

Densities of post-settlement junipers were consistently greater in plots located near existing juniper stands vs. plots in similar land-cover classes but farther from juniper (in other words, "near" vs. "far" strata). These results confirm the greater likelihood of juniper seed dispersal and subsequent establishment of trees within 1600 m of juniper stands. Birds are the most important disseminators of western juniper seeds, especially at local scales (Chambers and others 1999; Miller and others 2005). Although most seeds are deposited near the source tree, frugivorous mammals or flocks of birds such as American robins (*Turdus migratorius*), bluebirds (Sialia spp.), or waxwings (*Bombycilla* spp.) may disperse seeds several kilometers away (Chambers and others 1999). Increasing densities of seed-bearing trees, and thus seed availability, increase the likelihood of longer dispersal events (Chambers and others 1999).

[4]Phases of woodland development have been described as follows: Phase I, trees are present but shrubs and herbs are the dominant vegetation that influence ecological processes on the site; Phase II, trees are co-dominant with shrubs and herbs and all three vegetation layers influence ecological processes on the site; and Phase III, trees are the dominant vegetation and the primary plant layer influencing ecological processes on the site (from Miller and others 2008).

Multiple lines of evidence from our work suggest that low and mountain big sagebrush plots had the lowest levels of current juniper encroachment in the John Day province. This finding contrasts with work in the High Desert and Klamath provinces in southern Oregon and northern Nevada, where western juniper had encroached into mountain big sagebrush and low sagebrush communities more than any other sagebrush types (Miller and others 1999a). In our study, strata with the highest percentage of plots where juniper was absent were low and mountain big sagebrush sites, which typically occur at higher elevations that can be colder and/or more moist than is optimal for western juniper establishment (West and others 1978). These same environmental conditions in mountain big sagebrush sites also enhance restoration efforts; recovery in mountain big sagebrush is typically more rapid than in other sagebrush types following treatment to remove juniper (Miller and others 2005). Among our seven strata, low and mountain big sagebrush also had the lowest proportion of plots with pre-settlement junipers present, similar to results in studies in Oregon and Idaho (Johnson and Miller 2008). Miller and others (2005) noted the rarity of old trees or stumps in post-settlement juniper communities associated with mountain big sagebrush. Finally, canopy cover of juniper was lowest in the low and mountain big sagebrush strata.

In contrast to existing levels of encroachment, low and mountain big sagebrush sites may be at high risk of future woodland expansion in the John Day province. These two strata were the only ones in which juniper densities were greatest in the 0.3 to 1 m size class (table 4), suggesting relatively recent tree establishment but future growth and infilling. Johnson and Miller (2006) estimated a mean of 90 years for invaded mountain big sagebrush sites to reach Phase II. Historically, fire return intervals of < 50 years in mountain big sagebrush were probably adequate to suppress the encroachment of western juniper. However, sharp declines in fire frequency in mountain big sagebrush were reported beginning in the late 1800s, resulting in increased opportunities for western juniper establishment in these plant communities (Miller and others 2005). Thus, mountain big sagebrush may be highly susceptible to future encroachment of western juniper (Johnson and Miller 2006), especially in our study area.

Our finding of decreasing canopy cover of sagebrush with increasing canopy cover of juniper corroborates results of previous studies (Blackburn and Tueller 1970; Bunting and others 1999; Miller and others 2005; Tausch and Tueller 1990), although this relationship is not universal (for example, see Gedney and others 1999; Knapp and Soulé 1998). As juniper crown cover increases, understory composition changes, with decreasing understory diversity and eventual loss of the shrub component (Bunting and others 1999; Gedney and others 1999; Miller and others 1999a). Sharp increases in shrub canopy cover also are seen following removal of juniper (Miller and others 2005).

The ubiquity of juniper in our sampling plots was not expected; 152 (85 percent) of our plots were mapped as sagebrush-dominated ecological systems by LANDFIRE. Yet in 53 (35 percent) of these plots, canopy cover of juniper exceeded 10 percent, the threshold for mapping juniper woodlands. These results, along with other explorations of land cover as mapped by LANDFIRE EVT in central Oregon, strongly suggest that western juniper is under-represented and sagebrush communities over-represented by LANDFIRE (data on file with the PNW Research Station, La Grande Forestry and Range Sciences Laboratory, La Grande, OR).

Most juniper in Oregon occurs on private lands (Gedney and others 1999), thus management of this resource by public agencies must be closely coordinated among all stakeholders to ensure that comprehensive treatment strategies are successful (Azuma and others 2005). Management actions for western juniper should be preceded by the setting of precise goals and objectives for the management program, such as describing the desired ecological conditions (Miller and others 2007). Other steps include: (1) identifying the ecological site (for example, soils, potential natural vegetation), (2) assessing current conditions on the site, (3) considering the landscape in which management is planned, and (4) selecting appropriate treatments, such as prescribed fire or mechanical removal (Miller and others 2007).

In summary, the densities and size distribution of juniper trees that we observed pose substantial risk to sagebrush communities in central Oregon. Questions remain about the extent of sagebrush that has been invaded recently by western juniper versus communities that historically supported woodlands. However, our findings suggest that within sagebrush communities of the John Day province, intensive management through removal of encroaching western juniper may be prudent, while retaining old-growth juniper stands.

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