Age Structure and Expansion of Piñon-Juniper Woodlands: A Regional Perspective in the Intermountain West

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Abstract

Numerous studies have documented the expansion of woodlands in the Intermountain West; however, few have compared the chronology of expansion for woodlands across different geographic regions or determined the mix and extent of presettlement stands. We evaluated tree age structure and establishment for six woodlands in four ecological provinces in the central and northern Great Basin. Since 1860, the area occupied by piñon and or juniper has increased 125 to 625 percent. The increase of trees was a result of infill into shrub-steppe communities with relatively open low density stands of trees and expansion of piñon and juniper into sagebrush-steppe communities that previously did not support trees. Woodland expansion in Oregon, Utah, and Nevada were similar, but began two to three decades earlier in Idaho. The majority of woodlands are still in the early to mid phases of stand closure, which means they often support an understory of shrubs and herbaceous vegetation. This has implications for future changes that will occur within these woodlands in the next 30 to 50 years. In the absence of disturbance or management, the majority of these landscapes will become closed woodlands resulting in the loss of understory plant species and greater costs for restoration.

Key words: western juniper, Utah juniper, singleleaf piñon, succession, chronology, old-growth

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Introduction

Piñon and juniper woodlands in the cold desert of the Intermountain West occupy over 18 million ha (44,600,000 acres) (Miller and Tausch 2001). These woodlands are commonly associated with sagebrush (*Artemisia*) communities forming a mosaic of shrub-steppe and woodlands across landscapes. Numerous studies have documented the expansion of these woodlands resulting in the replacement of shrub-steppe communities (Adams 1975; Burkhardt and Tisdale 1976; Cottam and Stewart 1940; Gedney and others 1999; Miller and others 2005; Miller and Rose 1995, 1999; Tausch and West 1988, 1995; Tausch and others 1981). However, few have documented woodland dynamics at the landscape level and across different ecological provinces. This has resulted in uncertainties as to the extent of piñon and juniper woodlands that have replaced or are encroaching sagebrush-steppe communities versus sites that have supported woodlands in the past.

As a result of continued expansion during the 20th century, control of piñon and juniper has involved a major effort by both government agencies and private landowners since the early 1960s. The increase in piñon and juniper dominance within Intermountain plant communities can have significant impacts on soil resources, plant community structure and composition, forage quality and quantity, water and nutrient cycles, wildlife habitat, biodiversity, and fire severity and frequency (Miller and others 2005, Miller and Tausch 2001). However, in the 1970s various groups began challenging the removal of piñon and juniper woodlands in the Intermountain West (Belsky 1996). One area of concern was the limited scientific evidence documenting the expansion of these conifers at a broad scale (in other words, landscapes or entire woodlands) in the Intermountain Region. The fear of many groups is historic woodlands that occupied landscapes prior to Eurasian settlement in the late 1800s are being burned, cut, and chained. In the past, many treatments did not differentiate between post (historic) and presettlement woodlands (defined here as trees or woodlands <140 years old and >140 years old, respectively). If the primary emphasis of restoration is to restore and maintain potential natural vegetation, then understanding the mix of historic stands of trees with sagebrush-steppe communities and recently developed woodlands at the landscape scale becomes essential in the development of maintenance and restoration strategies for Intermountain plant communities.

The goal of our study was to document the temporal and spatial dynamics of tree establishment and expansion for piñon (*Pinus monophylla*) and two juniper species (*Juniperus osteosperma* and *J. occidentalis* ssp. *occidentalis*) across several different geographic regions in the Intermountain West. We also wanted to determine the ratio of post and presettlement trees for western juniper, Utah juniper, and singleleaf piñon alliances across these geographic locations. To accomplish this, we evaluated six woodlands from their lower to upper elevational boundaries in four different ecological provinces using both extensive and intensive sampling procedures. Questions we addressed in this study were:

1. What was the temporal pattern of woodlands expansion into sagebrush-steppe plant communities?
2. What was the chronological sequence of tree establishment?
3. What was the density and spatial extent of historic trees?
4. What is the current successional state of woodlands development?

The extent of woodland expansion is not always clear and has lead to debate and court appeals over proposed tree removal projects. The possible removal of old trees (>140 years old) or presettlement woodlands that are recovering from disturbance has resulted in considerable concern from a number of interest groups throughout the West. Addressing the above questions will help land managers develop tree removal projects that will more closely restore vegetation to presettlement conditions.

Study Area

The study was located in four ecological provinces in Idaho, Oregon, Nevada, and Utah (fig. 1), and included western juniper, Utah juniper, and singleleaf piñon.

Owyhee Mountains Idaho and Steens Mountain Oregon: Western Juniper

The study areas in the western juniper alliance were located on Steens Mountain in southeastern Oregon and in the Owyhee Mountains in southwestern Idaho (fig. 1). Climate, soils, and vegetation across the study areas are characteristic of those found throughout much of the range of western juniper in the High Desert, Klamath, and Humboldt ecological provinces. In Idaho, we sampled the woodlands on Juniper and South Mountains located in the Owyhee Mountains

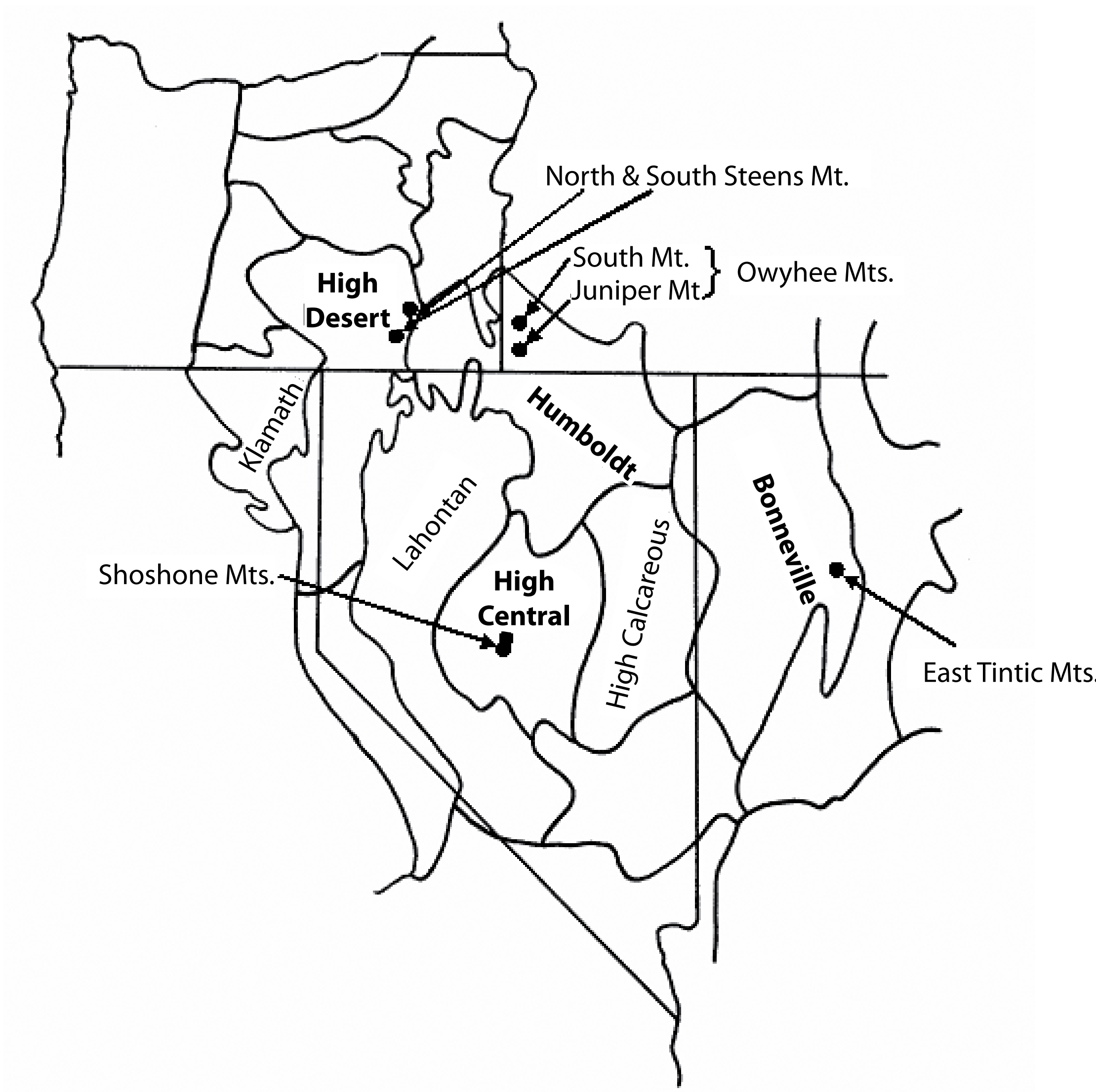


Figure 1. Map of the seven study locations (Ecological Provinces derived from Anderson and others 1998 and Bailey 1994). Ecological provinces sampled are indicated by **bold** lettering.

in Owyhee County (42° north latitude, 116° west longitude) in the Humboldt Ecological Province. This area is managed by the Boise District of the Bureau of Land Management. The geomorphology of this area is characterized as an uplifted region with doming and fault blocking common. The Owyhee Mountains are predominantly comprised of granite; however, most of the uplands are rhyolites and welded tuffs with silicic volcanic flows, ash deposits, and wind-blown loess. Topographic characteristics of this area include mountains dissected by deep canyons, rocky tablelands, and rolling plains ranging in elevation from 1200 to 2375 m (3936 and 7790 ft). Woodlands described in Oregon were located on the north and south portions of Steens Mountain in the High Desert Ecological Province and managed by the Burns District of the Bureau of Land Management. Steens Mountain is an isolated volcanic fault-block that lies in the extreme northwest Basin and Range Province (Fenneman 1931) in Harney County, south-southeast of Burns (42° north latitude, 118° west longitude). The mountain is approximately 80 km (50 mi) long and oriented in a northeast direction (Orr and Orr 1999). The elevation of Steens Mountain ranges from 1268 to 2949 m (4160 to 9673 ft), with a steep east-facing escarpment and a gentle west-facing slope. Geomorphology of Steens Mountain is characterized as nearly level basins and valleys that are bordered by long, gently sloping alluvial fans. Pliocene volcanic and shallow intrusive igneous rocks occur, along with andesite, breccias, and basalt flows. Alluvial deposits, playas, marshes, and flat deposits occur in the valleys.

Climate across the Owyhee Mountains and Steens Mountain is characteristic of the northern Great Basin in that it is cool and semiarid. Mean annual precipitation within the juniper belts varies between 300 mm (11.8 in) at lower elevations increasing to >400 mm (15.7 in) at higher elevations. The majority of the annual precipitation is received as snow in November, December, and January and as rain March through June. Average temperatures vary from -6.6 °C (20.2 °F) in January to 34.5 °C (94.1 °F) in July. The growing season varies from 90 to 120 days. Soils range from shallow rock outcrops to moderately deep gravelly, sandy, or silt loams. Predominant soil taxa are Aridisols, Entisols, Alfisols, Inceptisols, and Mollisols that occur in combination with mesic and frigid soil temperature regimes and xeric and aridic soil moisture regimes. Cryic temperature regimes occur at higher elevations typically above the western juniper woodlands belt.

Western juniper woodlands form a discontinuous belt between 1450 and 2100 m (4760 to 6890 ft) in elevation on Steens Mountain and a near continuous belt between 1300 and 2100 m (4265 to 6890 ft on South and Juniper Mountains). Above 2100 m (6890 ft), extremes in temperatures limit western juniper establishment (Miller and Rose 1995). Limited western juniper distribution in the basins or below the toe-slopes of the mountains is likely an artifact of late spring frosts (Billings 1954) coupled with limiting moisture. The National Resources Conservation Service has described the areas potential natural vegetation as sagebrush-grassland. Current vegetation is predominantly of two types, sagebrush-grasslands and western juniper woodlands (Burkhardt and Tisdale 1976; Johnson 2005; Miller and others 2000). Predominant potential vegetation occupying the uplands are: 1) mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) (Cronquist and others 1972) associated with bluebunch wheatgrass (*Psuedoroegneria spicata*), Idaho fescue (*Festuca idahoensis* Elmer), western needlegrass (*Acnatherum occidentalis*), and Thurber needlegrass (*Acnatherum thurberianum*) on relatively deep, well-drained soils; and 2) low sagebrush (*Artemisia arbuscula* ssp. *arbuscula*) associated with bluebunch wheatgrass, Idaho fescue, or Sandberg bluegrass (*Poa secunda*) over restrictive layers of claypan or bedrock (Burkhardt and Tisdale 1976; Johnson 2005). Scientific nomenclature follows Cronguist and others (1972-2005).

Shoshone Mountains Nevada: Piñon Pine and Utah juniper

The study site in Nevada was located on the Shoshone Mountains in Nye and Lander counties of central Nevada, about 56.3 km (35 mi) southwest of Austin, Nevada, in the High Central Ecological Province (fig. 1). Sample locations are on land managed by both the Austin District of the Humboldt-Toiyabe National Forest and the Battle Mountain District of the Bureau of Land Management. The Shoshone Mountains are a typical north-south trending mountain range characteristic of the Basin and Range topography of the Great Basin, and the section where the study is located is approximately 80.5 km (50 mi) long. Elevations of the valley bottoms to the east and west range from 1800 to 2000 m (5900 to 6560 ft), and elevations of the peaks range from 2550 to 3140 m (8366 to 10,302 ft). The geomorphology of the Shoshone Mountains includes gently sloping valleys on either side, alluvial fans at the mountain base, and relatively steep mountain slopes. The North Shoshone Peak area, where the study is located, represents the remnant of a caldera with a lithology that consists primarily of welded and non-welded silica ash flow tuffs.

Climate in the region is the characteristic cool and semiarid climate of the central Great Basin. Average annual precipitation in the woodlands belt ranges from 230 mm (9.1 inches) at the base of the mountain to over 600 mm (23.6 inches) on the mountain peaks. The majority of the precipitation comes as winter snow and spring rains. Average annual temperatures in Austin, Nevada, range from -7.2 °C (19.0 °F) in January to 29.4 °C (84.9 °F) in July. Soils are generally extremely coarse grained gravelly loams that have a weak to moderate structure. Some sandy or silt loams are present but limited in distribution.

The woodlands across the Shoshone Mountains, form a continuous to sometimes discontinuous belt between about 2050 and 2700 m (6725 and 8860 ft) elevation with stands at the highest elevation on southerly aspects. Sagebrush-grasslands and pinyon-juniper woodlands are the predominant vegetation types. Characteristic species include Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) at lower elevations and mountain big sagebrush at higher elevations. Shallow soils, particularly on broad ridge tops and adjacent slopes at higher elevations, are dominated by low sagebrush. Perennial grasses include Sandberg bluegrass, bottlebrush squirreltail (*Elymus elymoides*), Needle and thread (*Hesprostipa comata*), Thurber needlegrass, Idaho fescue, and bluebunch wheatgrass. Numerous forb species are also present. Cheatgrass (*Bromus tectorum*) is not a large component in the area. Woodlands are all single-leaf pinyon dominated with scattered presence of Utah juniper. At the upper elevational boundary of the pinyon-juniper woodlands are found pockets of curl-leaf mahogany (*Cercocarpus ledifolius*).

East Tintic Mountains Utah: Piñon Pine and Utah juniper

The Utah study site was located in the East Tintic Mountains of the eastern Great Basin about 9.7 km (5 mi) northwest of Eureka and about 48.3 km (30 mi) southwest of Provo in the Bonneville Ecological Province. The portion of the woodlands sampled was from Broad Canyon over the East Tintic Mountain Range summit (latitude, 40°01' N; longitude, 112°15' W) to Black Rock Canyon in Utah and Tooele counties. The area is managed by the Salt Lake District of the Bureau of Land Management. The East Tintic Mountains are composed of two relatively parallel ranges of north-trending fault-block ridges near the eastern edge of the Great Basin (Stokes 1986). They are world famous for rich ore deposits that have been discovered and mined. The northern part of the range, including Black Rock and Broad canyons, is composed of Paleozoic limestones, dolomites, and shales. Tertiary intrusives are present in a few places in Broad Canyon and have been extensively mined further south in the Eureka area. Southern and eastern parts of the range consist of Tertiary basalt and volcanic ash. The East Tintic Mountains may be thought of as the eroded remnants of a large composite volcano whose eruptions buried a pre-existing structurally complex mountain range (Stokes 1986). Boulter Peak at 2532 m (8305 ft) is the highest elevation in the East Tintic Mountains. The mouth of Black Rock Canyon (running east from the south end of Rush Valley) is 1920 m (6300 ft) in elevation and the mouth of Broad Canyon (running south from the south end of Cedar Valley) is 1630 m (5350 ft) in elevation.

Precipitation ranges from 203 to 254 mm (8 to 10 inches) in the valleys to about 30.5 cm (12 inches) at the base of the mountains to as much as 660 mm (26 inches) at the highest elevations. Much of the precipitation is in the form of winter snow and spring rains. In Eureka, Utah, elevation 2000 m (6560 ft), 39°57' N latitude, 112°07' W longitude, the average maximum daily annual temperature is 14.5 °C (59.2 °F), ranging from 2.1 °C (36.4 °F) in January to 30.0 °C (86.0 °F) in July (Ashcroft and others 1992).

The vegetation is dominated by Wyoming big sagebrush and black sagebrush (*Artemisia nova*) at low elevations giving way to a piñon-juniper woodlands, then to mixed conifer (*Abies concolor, Psuedotsuga menziesii*) on north facing slopes at higher elevations (West 1989), with mountain mahogany on exposed ridges and bigtooth maple (*Acer grandidentatum*) in canyons. Scrub oak (*Quercus gambellii*), common on the nearby Wasatch Mountains, is not present. The woodlands and conifer stands are interspersed and underlain by black sagebrush or mountain big sagebrush, mountain brush species (*Purshia* sp., *Amelanchier* sp., *Symphoricarpos oreophilus, Pachystima myrsinites*), bluebunch wheatgrass and Indian ricegrass (*Acnatherum hymenoides*), and mountain phlox (*Phlox austromontana*) and Mojave sandwort (*Arenaria macradenia*). More common grasses and forbs associated with Wyoming big sagebrush are western wheatgrass (*Pascopyrum smithii*), Sandberg bluegrass, and desert alyssum (*Alyssum desertorum*). At higher elevations, muttongrass (*Poa fendleriana*), needle and thread, and tall fescue (*Festuca arundinacea*) become more common.

Methods

To gain a landscape scale perspective of both spatial expansion and development of piñon and juniper woodlands in 2001, we established seven primary transects varying in length from 14 to 24 km (8.7 to 15 mi) across six different woodlands. Each transect was located along an elevational gradient, which extended from the lower to upper boundaries of each woodland. We used both field reconnaissance and aerial photos to establish transects in areas where there was minimal evidence of woodlands disturbance and to ensure sampling represented a wide array of environmental variables typical of sites occupied by juniper and piñon.

Along each primary transect, circular plots for the extensive sample were placed approximately every 500 m (1640 ft) along three parallel transects spaced roughly 500 m (1640 ft) apart (fig. 2). Total number of plots sampled/transect varied from 69 to 99. We

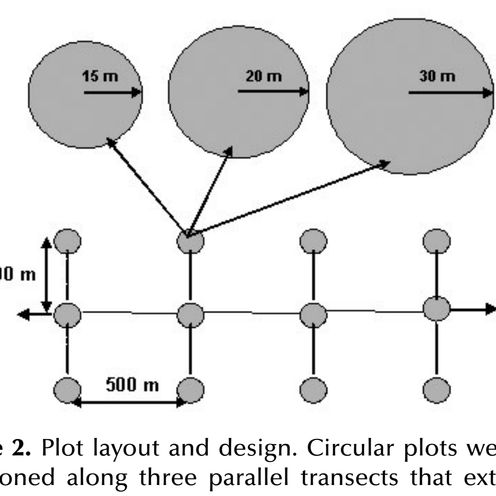


Figure 2. Plot layout and design. Circular plots were positioned along three parallel transects that extended from the low to upper elevation boundaries of a woodland.

adjusted plot locations to fit within a uniform stand of at least 0.5 ha (1.2 acres) in size and representing a single ecological site with uniform characteristics (for example, aspect, topography, soil, and vegetation). A variable plot radius was employed to improve sampling efficiency. At each location the plot radius was selected based on a cursory estimation of stand density: 15, 20, and 30 m (49.2, 65.6, and 98.4 ft) radiuses were employed on plots with greater than 600 trees/ha (240/acres), between 200 and 600 trees/ha (80 to 240/acres), and with less than 200 trees/ha (80/acres), respectively. Densities of presettlement trees were always counted in a 30 m radius plot. We identified and recorded dominant understory plant species and remnants of stumps and logs to determine the potential plant alliance and association.

In each extensively sampled plot, we also identified the phase of woodlands development (in other words, I, II, III or early, mid, and late successional) following the guidelines developed by Miller and others (2000, 2005) (table 1). Phases are described as:

- 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.

Tree canopy cover during Phase I is typically less than 10 percent and is comprised primarily of juveniles (<1 m [3.3 ft]) and saplings (1 to 3 m [3.3 to 9.8 ft]). Phase II stands are generally composed of young trees interspersed with older dominant trees (typically 80 to 140 years). Tree cover in Phase II commonly approaches 10 to 49 percent, depending on the ecological site. Characteristics employed for differentiating between Phases II and III include estimating terminal and lateral leader growth and evaluating the status of the shrub layer. In Phase III terminal and lateral leader growth of understory trees are suppressed by intraspecific competition as stands approach a full stocking of dominant trees. Lateral leader growth in the lower 75 percent of the canopy is the first suppressed, typically <6 cm (2.4 inches). During Phase II, a portion the shrub layer remains intact but with obvious mortality taking place. In Phase III, live shrubs are largely absent and dead shrub skeletons are common to abundant.

Density of pre- and postsettlement trees was measured in each extensively sampled plot. Presettlement juniper trees were identified in the field using morphological characteristics described by Waichler and others (2001) and Miller and others (2005). For piñon, we used similar characteristics including flat tops and bark. We determined if a stand replacement tree disturbance had occurred on the plot (in other words was the stand treeless prior to postsettlement establishment) by recording standing and down dead trees and charred tree remnants. We also used these data to estimate the

Table 1. Stand characteristics differentiating the three transitional phases of woodland succession for several mountain big sagebrush associations, including Thurber needlegrass (maximum juniper cover = 25 to 41 percent, Idaho fescue (maximum juniper cover 34 to 58 percent), and Columbia needlegrass (maximum cover = 60 to 75 percent) (derived from Miller and others 2000).

Characteristics (post-settlement stands)	**Phase I (early)**	**Phase II (mid)**	**Phase III (late)**
Tree canopy (percent of max)	open, actively expanding ≤10	actively expanding 10 to 30	expansion nearly stabilized >30
Leader growth (dominant trees) (cm/yr)	terminal >10 lateral >10	terminal >10 lateral 5 to10	terminal >10 lateral <5
Crown lift[1] (dominant trees)	absent	absent	lower limbs dying or dead where tree canopy >40 percent
Potential berry production	low	moderate to high	low to near absent
Tree recruitment	active	active	limited primarily to beneath trees or absent
Leader growth (understory trees) (cm/yr)	terminal >10 lateral >8	terminal >10 lateral 2 to >8	terminal <5 lateral <2
Shrub layer	intact	nearly intact significant thinning	≥75 percent dead

[1] Crown lift is the mortality of lower tree limbs, usually due to shading by neighboring trees.

density of piñon or juniper prior to a stand replacement disturbance. Plots occupied by pre- and postsettlement trees and/or large charred stumps or logs were named mixed aged stands and plots with no evidence of presettlement trees were named postsettlement.

To estimate the time when the first trees established in sagebrush-grassland communities across the six woodlands, we aged the three largest trees on all plots. An increment core was collected at 30 cm (11.8 inches) above ground level. Cores were air-dried, mounted, sanded until the cell structure was visible with a binocular microscope, and rings counted. Most cores (98 percent) intersected or were within 10 rings of the pith. For samples that did not include the pith, we used transparent overlays of concentric circles to estimate the number of rings to pith (Villaba and Veblen 1997). Thirty juvenile trees (15 to 45 cm [6 to 18 in]) growing in the tree interspace of open (Phase I) woodlands were sampled and aged to correct for core sample height (Johnson and Miller 2006).

To measure the chronology of woodlands development at the stand level, we intensively measured a sub-sample of approximately 25 percent of the extensively sampled stands in three of the six woodlands (Juniper Mountain, Idaho; East Tintic, Utah; and Shoshone Mountain, Nevada). On Juniper Mountain three 6 by 60 m (20 by 197 ft) belt transects were established for tree measurements in each intensive plot. On the East Tintic and Shoshone Mountains, a 20 by 50 m (65.5 by 164 ft) (0.1 ha) plot was used for tree measurements on each intensive plot. Tree density was determined by counting each tree rooted in the three, 6 by 60 m (20 by 197 ft) belt transects or all trees in the 20 by 50 m (65.5 by 164 ft) plot in one of the tree classes described in the procedures for the extensive plots. An increment core was collected from trees greater than 6 cm (2.4 inches) in basal diameter 30 cm (11.8 inches) above ground level. Cross-sections at ground level were collected from trees smaller than 6 cm in basal diameter for aging. We aged a minimum of 40 trees in each plot within the 6 by 60 m (19.6 by 197 ft) belt transects. If 40 trees did not occur within the three transects, we randomly selected additional trees immediately to the belt transects.

Samples from all sites were mounted and sanded and rings were counted. If coring missed the pith, the pith radius was estimated graphically (Villaba and Veblen 1997). On each of the three mountain ranges, a sample of 30 juveniles (15 to 45 cm [6 to 18 inches]) was collected from interspace areas and the mean age of a tree 30 cm (12 inches) tall was determined to correct age for core sample height.

Analysis

Differences in age structure among the six different woodlands were determined using the Kolmogorov-Smirnov nonparametric test to compare age class distributions and the Kruskal-Wallis test to compare average age at $p = 0.05$ (Zar 1984).

Results

Woodlands Chronology

Woodlands expansion and infill

Our extensive and intensive data suggests large increases in piñon and juniper started after 1850 across all six locations as a result of infill into open low density presettlement tree stands in sagebrush-steppe and expansion into sagebrush-steppe communities previously treeless. Trees establishing after 1860 accounted for 90 percent or more of the population measured in the extensively sampled plots (table 2). In Utah, Nevada, and Oregon, trees establishing prior to 1860 accounted for only 2 percent or less of the total population of piñon and juniper. In Idaho, presettlement trees were more abundant across the landscape, accounting for 5 to 10 percent of the population. Prior to 1860, mean tree densities based on live trees, stumps, and

Table 2. Proportion of pre- (>140 years) and postsettlement (<140 years) trees and total tree densities in the extensively sampled plots, based on tree morphology and aging the three largest trees.

	Old-growth (percent)		Post-settlement (percent)		Total	# Trees
	piñon	juniper	piñon	juniper	trees/ha	sampled
East Tintic, UT	0.8	1	99.2	99	885	4646
Shoshone, NV	0.6	1.5	99.4	98.5	344	3741
South Mt., ID	-	5	-	95	197	4843
Juniper Mt., ID	-	10	-	90	537	4332
South Steens, OR	-	1	-	99	282	2816
North Steens, OR	-	2	-	98	264	3345

Table 3. Proportion of stands with one or more trees older than 140 years (mixed aged), and stands with all trees less than 140 years (postsettlement) in the extensively sampled plots.

Site	Mixed aged plots (percent)	Postsettlement plots (percent)	Number of plots
East Tintic, UT	20	80	75
Shoshone, NV	22	78	87
South Mt., ID	67	33	87
Juniper Mt., ID	48	52	69
South Steens, OR	16	84	78
North Steens, OR	30	70	99

logs across South Mountain and Juniper Mountain, Idaho were 20 and 27/ha (8 and 11/acres), respectively. Frequency of occurrence of presettlement trees in the extensively measured plots in the six woodlands varied from 16 to 67 percent (table 3). In Oregon, Nevada, and Utah, presettlement trees occurred on 16 to 30 percent of the extensive sampled stands in each state. However, in Idaho, presettlement trees occurred on nearly half or more of stands.

Temporal pattern of woodlands expansion into shrub-steppe

The lack of large remnant wood or standing presettlement trees inferred nearly two-thirds of the landscapes measured were treeless prior to 1860. The period of most rapid expansion of piñon and juniper occurred between 1900 and 1920 in Utah, Nevada, and Oregon and 1880 to 1920 in Idaho (fig. 3). By 1920, 50 to 73.5 percent of the sagebrush-steppe communities had been encroached by juniper and or

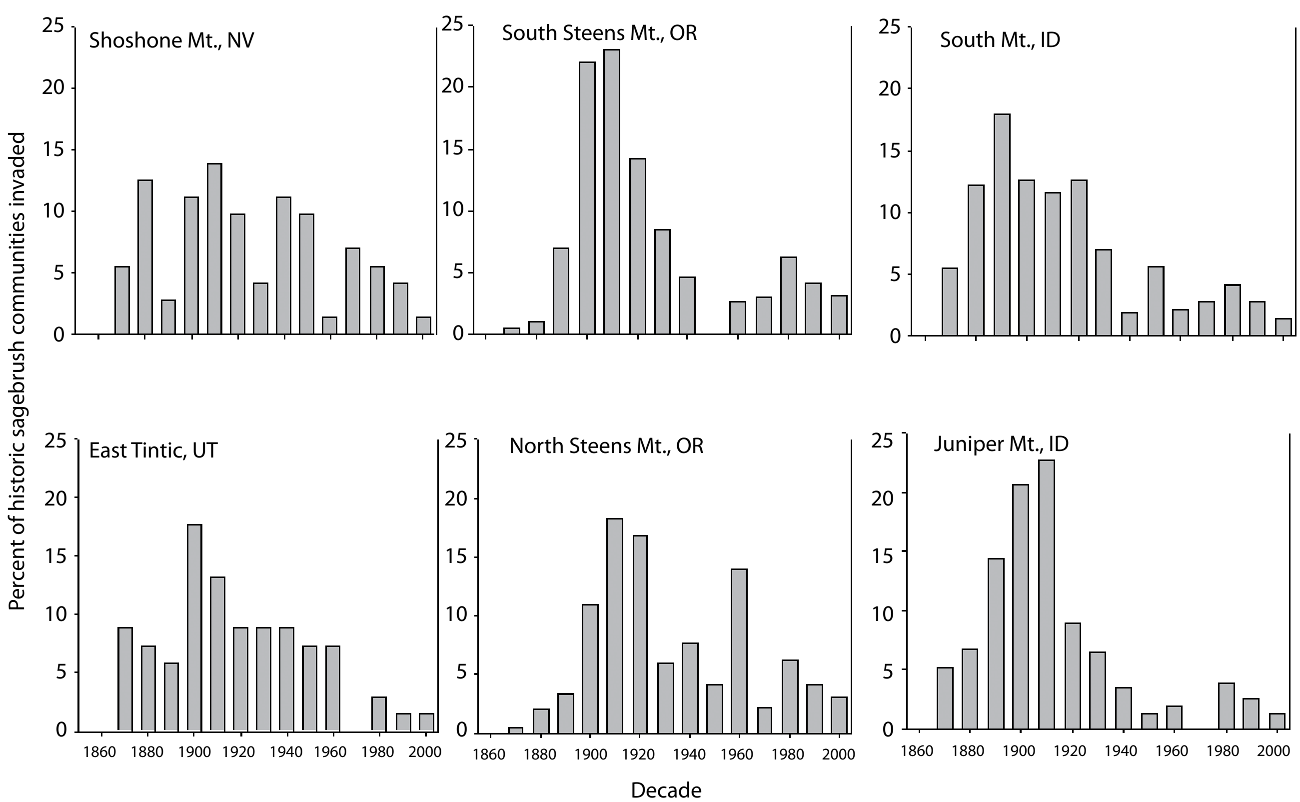


Figure 3. The proportion of decadal encroachment of piñon and/or juniper between 1860 and 2000 into historic sagebrush-steppe stands with no evidence of presettlement trees.

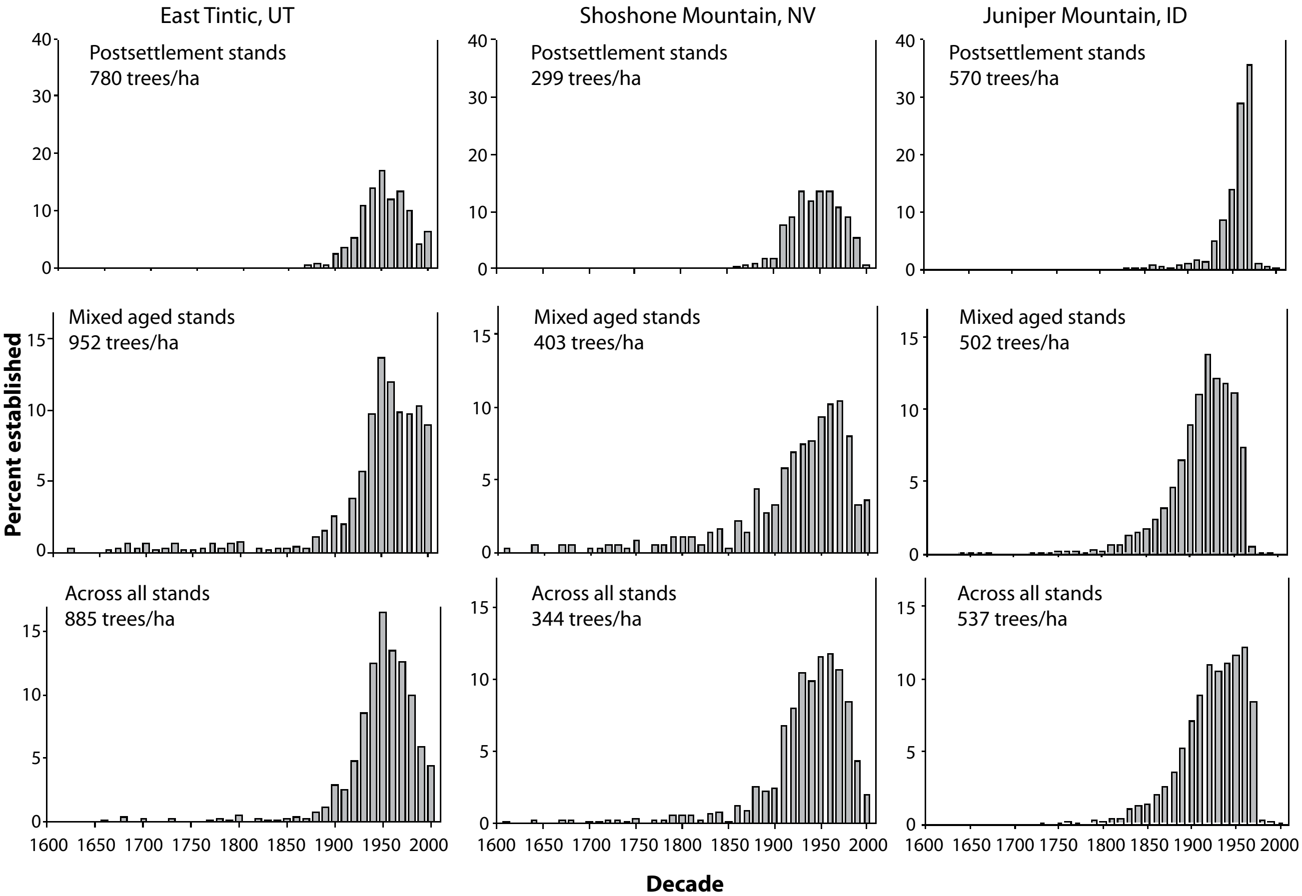


Figure 4. Current mean tree density and decadal establishment of piñon and juniper for postsettlement and mixed aged stands, and averaged across all stands for each location. Postsettlement stands are composed of trees establishing after 1860 and contain no evidence of trees (stumps or snags) that established prior to 1860. Mixed aged stands are composed of trees that established prior to and after 1860. Across all stands represents decadal establishment for the entire woodland at each geographic location.

piñon. Although woodlands have continued to expand, rates of expansion have decreased since 1950 compared to the first half of the 20th Century, possibly resulting in a decline in treeless plant communities open for first time expansion. In Idaho, expansion into sagebrush-steppe communities occurred at a faster rate during the late 1800s compared to the other regions. In the two Idaho woodlands, western juniper had encroached 75 and 78 percent of the mountain big sagebrush stands previously treeless by 1920. By the end of the 20th Century, trees remained absent on 32 and 13 percent of the plots on the Shoshone and East Tintic Mountains, respectively, and absent on only 7 and 2 percent of the plots in Idaho and Oregon, respectively.

Temporal pattern of tree establishment

Tree establishment in both mixed age (infill) and shrub-steppe (expansion) began to increase after 1850 and retained relatively high rates well into the 20th Century, declining after 1950 (fig. 4). Rates of tree establishment between 1850 and 1900 appeared to be greater in mixed age stands than postsettlement stands. Although piñon and juniper followed the same general patterns of expansion and establishment across Utah, Nevada, and Idaho, the age structure of postsettlement stands was significantly different. The average age of trees in stands that developed after 1850 in Idaho were older ($p < 0.05$) than in Utah and Nevada, and the average age of trees in Nevada were older ($p < 0.05$) than in Utah. This was a result of an earlier beginning of tree establishment between 1860 and 1920 in Idaho compared to the other two locations (fig. 5). Total number of trees that established also differed across the three locations (fig. 4). Total density of Utah juniper trees in Utah was greater than woodlands in Oregon, Nevada, and Idaho.

Stage of woodlands development

The stage of development across all six woodlands varied from low density open stands of trees (Phase I) to dense closed stands (Phase III) (fig. 6). The majority

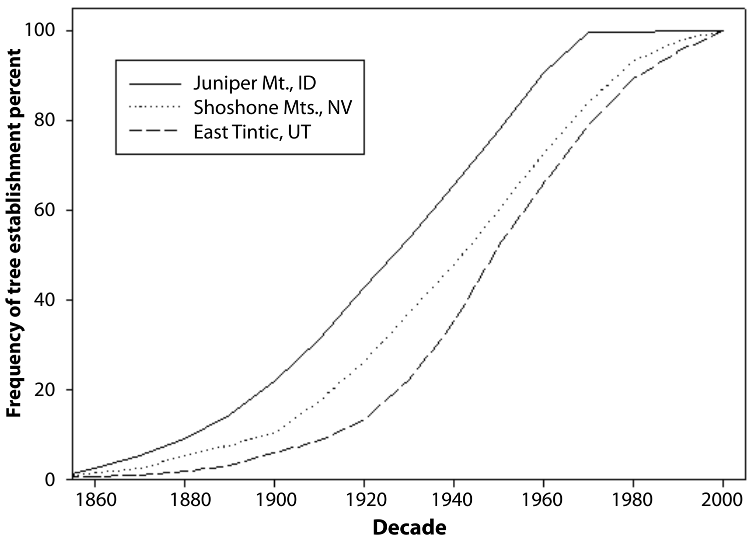


Figure 5. Accumulative frequency of decadal tree establishment since 1860 for three woodland populations in the intensive plots.

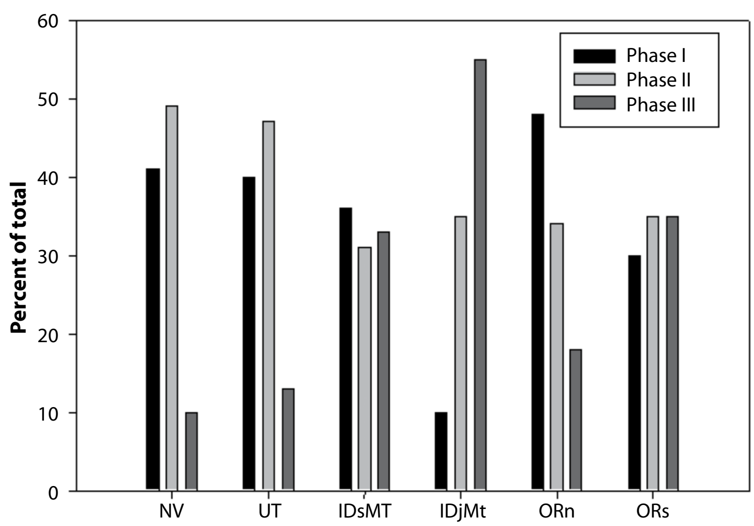
of stands along the Utah, Nevada, and north Steens, Oregon transects were still in the early to mid stages of woodlands development with less than 20 percent of the woodlands in Phase III. Stages of woodlands development in stands on South Mountain, Idaho and south Steens, Oregon, were nearly evenly split across all three Phases. Juniper Mountain, Idaho, was the only woodlands where over 50 percent of the stands were in Phase III. Initiation of tree establishment in stands currently in Phase I across Utah, Nevada, and Idaho occurred consistently later than stands in Phase II and III (fig. 7). In Phase I stands, tree establishment began slowly in the early 1900s and peak establishment occurred between 1960 and 1970. Declines in tree establishment have occurred across all three woodlands in Phase I during the last 2 to 3 decades of the 20th Century. However, the majority of Phase I stands have a high enough tree density to fully occupy the sites.

Discussion

Woodlands Expansion and Infill

For over 200 years prior to settlement, woodlands across all sites sampled were relatively low density with limited rates of establishment. Our data supported other work suggesting substantial increases in piñon and juniper have occurred in the Intermountain Region since the late 1800s (Burkhardt and Tisdale 1976; Cottam and Stewart 1940; Gedney and others 1999; Knapp and Soulé 1998; Miller and Rose 1995, 1999; Soulé and Knapp 2000; Tausch and others

Figure 6. The proportion of stands across extensive plots in each of the three different phases of woodland succession for the six study sites (Nevada = NV, Utah = UT, South Mountain Idaho = IDsMt, Juniper Mountain Idaho = IDjMt, North Steens Oregon = ORn, and South Steens Oregon = ORs). The average across all stands was 34 percent Phase I, 40 percent Phase II, and 27 percent Phase III. 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.



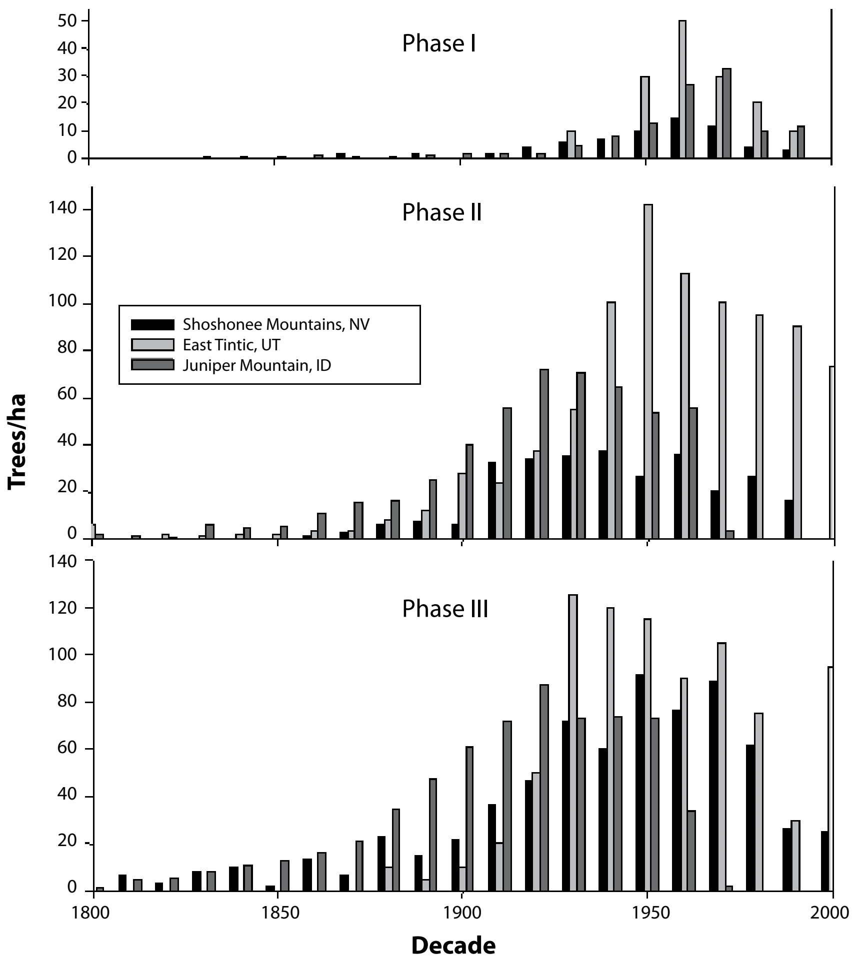


Figure 7. Establishment of piñon and juniper (trees/ha by decade) for each successional phase (Phases I, II, and III) in three woodlands across the intensive plots. Phase I—trees are present, but shrubs and herbs are the dominant vegetation that influence ecological processes on the site; Phase II—trees 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.

1981). Increases were the result of both infill in mixed age tree communities and expansion into shrub-steppe communities that appeared to not have supported trees over the past several centuries. Presettlement trees accounted for 5 and 10 percent of the population in Idaho and less than 2 percent on the remaining sites measured (table 2). This is similar to estimates reported for piñon and juniper woodlands in the Great Basin (Miller and others 1999; Miller and Tausch 2001). However, the proportion of old-growth can vary across different ecological provinces, resulting from different disturbance regimes, soils, and climate. Old-growth western juniper in the pumice-sand region of the Mazama Ecological Province is estimated to occupy over 50 percent of the stands (Miller and others 2005). Eisenhart (2004) documented that presettlement trees occupied the majority of stands measured on the Uncopahgre Plateau in western Colorado. And on Mesa Verde in Colorado, the majority of stands measured were composed of trees greater than 140 years old (Floyd and others 2000). This suggests some sites are capable of supporting persistent woodlands, possibly a consequence of soils and climate resulting in infrequent stand replacement disturbance regimes.

The shift from a relatively stable or limited rate of establishment to a substantial increase in conifer establishment in both space and time is generally attributed to the reduced role of fire, introduction of domestic livestock grazing, and shifts in climate (Burkhardt and Tisdale 1976; Heyerdahl and others 2006; Miller and Heyerdahl, in press; Miller and Rose 1999; Tausch 1999). Under current climatic conditions, conifers are likely to continue expanding into shrub-steppe plant communities (Betancourt 1987; Miller and others 2000; West and Van Pelt 1986).

Temporal Pattern of Woodlands Expansion into Shrub-Steppe

Since 1860, woodlands expansion across the six woodlands studied has resulted in the replacement of sagebrush-steppe plant communities. Evidence of presettlement trees (live, standing and down dead, and or remnants of large wood and charcoal) was found on 16 to 67 percent of the stands sampled, suggesting the current area occupied by trees has increased 140 to 625 percent since 1860. Gedney and others (1999) compared two U.S. Forest Service surveys conducted in 1938 and 1988 across eastern Oregon and reported a 600 percent increase in area occupied by western juniper. Cottam and Stewart (1940) also reported a 600 percent increase in area occupied by Utah juniper in southwest Utah between 1864 and 1940. In the Great Basin, old-growth trees have been reported by numerous authors to typically grow on rocky shallow or sandy soils that support little understory vegetation to carry a fire (Burkhardt and Tisdale 1976; Holmes and others 1986; Miller and Rose 1995, 1999; West and others 1998; Young and Evans 1981). In both the Idaho and Oregon woodlands, old-growth trees were associated with sites having a significantly greater cover of surface rock than where old-growth trees were absent (Johnson and Miller, in press). This was usually the case across all woodlands studied with the exception of the stands in Idaho. Within these woodlands, old-growth trees were found both on rocky, shallow soils and deep, well drained soils associated with mountain big sagebrush. In Idaho prior to the 1860s, trees occupied the landscape as widely scattered individuals or small stands of trees rarely exceeding a hectare, and accounted for 5 to 10 percent of the current population. This suggests a past fire regime characterized by frequent, lower intensity understory fires in open sagebrush/bunchgrass communities across much of the Owyhee Mountains. This fire regime resulted in a low density of widely scattered stands of trees, which is in contrast to the more commonly reported stand replacement fires that occur in woodlands (Baker and Shinneman 2004; Miller and others 2005; Miller and Tausch 2001) or fire return intervals and burn intensities that limited the development of mature trees in big sagebrush grassland communities (Miller and Rose 1999; Miller and Tausch 2001; Miller and Heyerdahl, in press).

The most rapid period of expansion occurred between 1880 and 1920, which also coincided with the most rapid period of tree establishment. We were surprised by the consistent decline in expansion rates across all of the woodlands after 1950. The decline may be attributed to several factors. Climatic conditions were relatively milder and wetter during the early compared to latter part of the 20th Century. A shift in climate beginning in the 1960s is also evident for many regions of the world (Kerr 2007). Mild wet climatic conditions enhance juniper seedling establishment (Fritts 1974; Fritts and Wu 1986). A second factor may be the reduced levels of sagebrush-steppe plant communities still open to invasion by piñon or juniper within the six landscapes measured. This is in addition to the decline in sagebrush cover resulting in a reduction in safe-sites for tree establishment.

Tree Establishment

In the mid to late 1800s, the number of piñon and juniper trees establishing per decade began to increase compared to the previous several hundred years. Across the six woodlands, presettlement trees densities averaged 5 to 27/ha (2 to 11/acre). Current stand densities range from 197 to 885 trees/ha (80 to 358/acre) (table 2) a 10- to 100-fold increase. The pattern of western juniper postsettlement establishment was similar to that of piñon and juniper in Utah and Nevada during this same period. Numerous other authors have reported increases in piñon, Utah juniper, and western juniper since the late 1800s (Adams 1975; Burkhardt and Tisdale 1976; Cottam and Stewart 1940; Gedney and others 1999; Miller and others 2005; Miller and Rose 1995, 1999; Tausch and West 1988, 1995; Tausch and others 1981). In Utah and Nevada, increased establishment rates of piñon and Utah juniper began after 1860. This is similar to the period reported by the majority of others surveying woodlands in the Intermountain Region (Adams 1975; Blackburn and Tueller 1970; Burkhardt and Tisdale 1976; Eddleman 1987; Gedney and others 1999; Gruell 1999; Miller and Rose 1995, 1999; Wall and others 2001). The timing of increased tree establishment after the 1860s in most areas is coincidental with the introduction of livestock and the reduction of fire occurrences (Swetnam 1993; Miller and Rose 1999).

Western juniper establishment across the Idaho woodlands, however, began to increase around 1850, occurring just prior to the introduction of livestock and following the end of the Little Ice Age. Several other authors have reported increased establishment just prior to 1860 (Tausch and others 1981, Tausch and West 1988). In Idaho, the early increase may be attributed to a shift to milder temperatures and wetter conditions following the end of the Little Ice Age (Antevs 1938; Graumlich 1987; LaMarche 1974; Wahl and Lawson 1970) in addition to greater potential seed source, a result of the greater abundance of presettlement trees. Johnson and Miller (in press) reported stands occupied by at least one tree >140 years initiated woodlands expansion 24 years earlier than stands lacking presettlement trees.

The general pattern of tree establishment was a gradual increase during the latter half of the 1800s and then a large increase during the early to mid 1900s followed by a decline in establishment during the second half of the 1900s. Other studies have reported tree establishment peaked during the first half of the 1900s (Burkhardt and Tisdale 1976; Gedney and others 1999; Miller and Rose 1999; Tausch and others 1981; Tausch and West 1988; Wall and others 2001). The increasing rate of establishment during the late 1800s and early 1900s may have been the consequence of optimal climatic conditions between 1850 to around 1920 and an increasing seed source resulting in an increasing population of seed disseminators. From 1850 to 1916 in much of the Great Basin, winters were generally milder and precipitation greater than the current long-term average (Antevs 1938; Graumlich 1987; LaMarche 1974; Wahl and Lawson 1970).

The rate of tree establishment occurred most rapidly in the two Idaho woodlands between 1860 and 1890, resulting in stands reaching closure (Phase III) more rapidly. Tree intraspecific competition in these stands started in the 1950s (Johnson and Miller 2006). The varying rates of tree establishment (figs. 4 and 5) are a function of the amount of seed input and success of seedling establishment on a site. Both woodlands in Idaho had the greatest density and distribution of presettlement trees, potentially resulting in a greater input of seed. Besides seed input, the timing and amounts of available water, temperature, and the abundance of safe sites (for example, beneath shrubs) are all factors that can influence the rate of tree establishment (Burkhardt and Tisdale 1976; Chambers 2001; Eddleman 1987; Everett and Ward 1984; Miller and Rose 1995).

The consistent decline in the number of trees establishing in the late 1900s across the three woodlands was not expected in Phase I stands. As trees increase in dominance and shrubs that provide safe sites for tree establishment decline (Miller and others 2000) we would expect a decline in establishment to occur during Phase II and be very limited in Phase III. However, we measured a general decline in establishment across all phases. This same trend has been reported on several other sites (Miller and Heyerdahl, in press). In addition to a decline in safe sites for tree establishment, this may be the result of climate, which in part would explain the decline in Phase I.

Stage of Woodlands Development

With the exception of the woodlands on Juniper Mountain, Idaho, almost 40 percent of the stands measured across the six woodlands were still in Phase I and another 40 percent in Phase II. This has implications for future changes that will occur within these woodlands (fig. 8). Assuming that past growth rates will continue into the future, tree dominated woodlands (Phase III) will increase from the current 20 to nearly 75 percent of the total woodland, within the next 30 to 50 years (Johnson and Miller 2006). Tree establishment started considerably later in stands in Phase I compared to stands in Phases II and III. During the transition from shrub-steppe to woodland, understory species, particularly the shrubs decrease (Miller and others 2000). The majority of this loss from increasing tree dominance has yet to occur in Phase I and

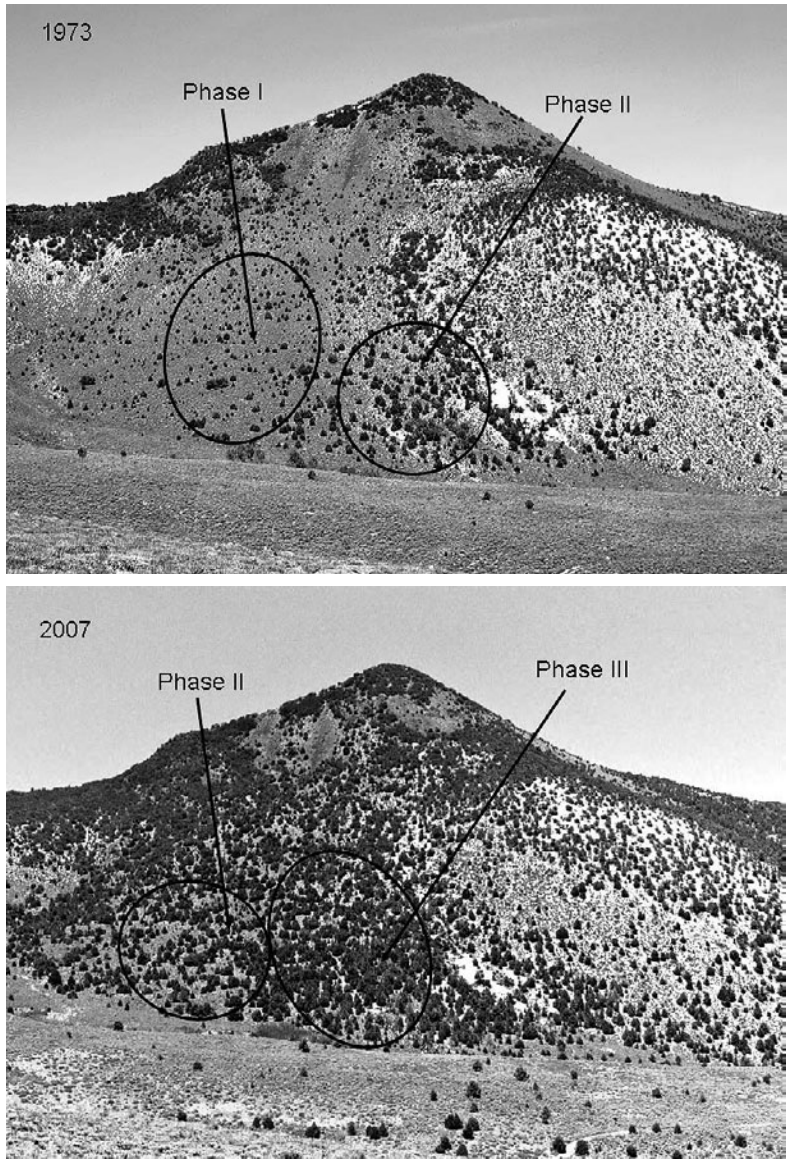


Figure 8. Woodlands closure over the 34-year period from 1973 to 2007, resulting in a shift from Phase I and II to Phase II and III in the Shoshone Mountains, Nevada (photos by Robin Tausch).

II woodlands. However, as stands approach Phase III, shifts in biomass over large areas from ground fuels to canopy fuels will significantly impact fire behavior. The more tree dominated piñon and juniper woodlands become, the less likely they are to burn under moderate conditions, resulting in infrequent high intensity fires. As Phase II approaches III, implementing prescribed fire, particularly in woodlands without a significant component of pinyon, becomes more difficult to apply in the absence some sort of mechanical pretreatment. This transition will occur on about half the current woodlands over the next 40 years. In addition, seed sources and other propagules of the understory species dramatically declines as the developing woodlands enter Phase III. The expansion and now increasing tree dominance in the resulting woodlands is putting remaining old-growth woodlands at increased risk of loss from high intensity fires (Tausch 1999). Scattered old-growth trees that are associated with sagebrush communities increases landscape heterogeneity, which can significantly increase the abundance and diversity of wildlife species (Reinkensmeyer and others 2007).

Management Implications

If management goals are to restore landscape function and processes to near presettlement conditions in the Great Basin, baseline information is needed that define the proportion of sagebrush-steppe and piñon-juniper woodlands on a landscape basis. Based on a broad examination of woodland age structure, our results indicate three general communities intermingled with one another at varying proportions across the landscape; (1) sagebrush-steppe with no trees, (2) sagebrush-steppe associated with a scattered low-density of trees, and (3) piñon and juniper woodlands. Their distribution is often determined by location specific interactions of slope, aspect, elevation, and topography. Prior to 1860 two-thirds of the landscape was treeless and occupied by sagebrush-steppe communities. Today, less than one-third of the landscape remains treeless and more than 90 percent of the trees have established since the 1860s. These data support active management in tree removal for over half of the landscape. In the absence of disturbance, woodlands will continue to expand, mature, and close, with the majority of these woodlands reaching Phase III over the next 40 to 50 years. To restore these landscapes managers should take the following steps:

- Inventory the distribution and density of presettlement trees, stumps or snags based on tree morphological characteristics defined by Miller and others (2006) to establish the proportion of shrub-steppe and woodland communities.
- Be sensitive to the presence of old-growth and develop their management plans accordingly to retain these trees and stands on the landscape.
- Emphasize treatments in woodlands in Phase I and II, particularly those on more productive sites with deeper soils, where treatment costs will be less and potential for success is greater than in Phase III woodlands.

The lack of active management will potentially result in the continued decline of historic sagebrush communities, structural diversity, understory species, herbaceous production, habitat for sagebrush obligates, and landscape heterogeneity. As a greater proportion of the landscape shifts towards Phase III the risk of larger, intensive wildfires and conversion to annual exotics will increase, as will the cost of treatment, and the potential for desirable outcomes will decrease. Infilling by younger trees also increases the risk for the loss of presettlement trees due to increased fire severity and size resulting from the increase in the abundance and landscape level continuity of fuels.

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