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A 40-Year Record of Tree Establishment Following Chaining and Prescribed Fire Treatments in Singleleaf Pinyon (*Pinus monophylla*) and Utah Juniper (*Juniperus osteosperma*) Woodlands

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Abstract

Chaining and prescribed fire treatments have been widely applied throughout pinyon–juniper woodlands of the western United States in an effort to reduce tree cover and stimulate understory growth. Our objective was to quantify effects of treatment on woodland recovery rate and structure and the relative dominance of the two major tree species in our Great Basin study area, singleleaf pinyon (*Pinus monophylla* Torr. & Frém.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little). We resampled plots after a 40-yr interval to evaluate species-specific differences in tree survivorship and establishment from posttreatment age structures. Tree age data were collected in 2008 within four chained sites in eastern Nevada, treated in 1958, 1962, 1968, and 1969 and originally sampled in 1971. The same data were collected at five prescribed burn sites treated in 1975 and originally sampled in 1976. All chained sites had greater juniper survival than pinyon survival immediately following treatment. Chained sites with higher tree survival also had the greatest amount of new tree establishment. During the interval between treatment and the 2008 sampling, approximately four more trees per hectare per year established following chaining than following fire. Postfire tree establishment only occurred for the initial 15 yr and was dominated by juniper. Establishment after chaining was dominated by juniper for the first 15 yr but by pinyon for 15–40 yr following treatment. Results support an earlier successional role for juniper than for pinyon, which is more dependent upon favorable microsites and facilitation from nurse shrubs. Repeated chaining at short intervals, or prescribed burning at infrequent intervals, will likely favor juniper dominance. Chaining at infrequent intervals ($>$ 20–40 yr) will likely result in regained dominance of pinyon. Chaining treatments can be rapidly recolonized by trees and have the potential to create or amplify landscape-level shifts in tree species composition.

Key Words: Great Basin, pinyon–juniper, rangeland restoration, tree age structure, tree regeneration, woodland expansion

INTRODUCTION

Over the past 150 yr, pinyon–juniper woodlands over much of the Great Basin ecoregion have increased dramatically in density and areal extent, in response to some combination of causal agents including climate change, overgrazing, altered disturbance regimes, and recovery from earlier wood harvesting (Miller and Wigand 1994; Weisberg et al. 2007). The resulting concerns over reduced forage for livestock, increased burn severity and fire risk, accelerated erosion (Pierson et al. 2007), and potential loss of species that are characteristic of sagebrush grasslands have led to widespread attempts to convert tree-dominated woodlands to grasslands dominated by native bunchgrasses or planted forage species. Such management treatments have commonly included mechanical treatments such as chaining, which has historically been accomplished by dragging a large anchor chain (7–11 $kg \cdot link^{-1}$) between two tractors to rip large shrubs and pinyon and juniper trees out of the soil (Ansley and Rasmussen 2005). Prescribed burning has been less commonly applied. Treatments have been implemented by a diverse group of government agencies and private entities, but have generally lacked monitoring efforts to determine long-term efficacy and ecological impact. Over the short term, both chaining and prescribed fire treatments may successfully reduce tree dominance and stimulate understory growth (Tausch and Tueller 1977; Everett and Ward 1984). However, because sites typically are not retreated at regular intervals, surviving trees can quickly grow and new trees establish when site conditions are suitable.

Quantitative monitoring investigations of posttreatment tree establishment are rare (Redmond et al. 2013), but necessary for evaluation of long-term treatment effects on tree establishment, density, and species composition. Analysis of posttreatment tree age structures allows reconstruction of the timing of tree establishment following chaining or prescribed burning, and helps us to understand how repeated applications of these treatments as a management regime is likely to alter landscape-level vegetation patterns. For example, Redmond et al. (2013) conducted repeat sampling of Colorado Plateau pinyon–juniper woodlands that had been chained 20–40 yr earlier, and observed that treated areas had less two-needle pinyon (*Pinus edulis* Engelm.) recruitment than untreated areas, whereas treatment did not appear to influence Utah juniper recruitment.

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Table 1. Environmental characteristics of the five study sites in eastern Nevada. Climate data are 30-yr normals (1981–2010).

Environmental characteristic	Blythe Springs	Spruce Mountain	South Kern	North Kern	White Pine
Annual precipitation (mm)	393	340	397	397	347
Minimum temperature (°C)	5.0	0.2	−1.0	−1.0	−1.9
Maximum temperature (°C)	17.3	13.6	13.0	13.0	15.1
Elevation (m)	1 768 to 1 981	1 951 to 2 134	2 164 to 2 195	2 164 to 2 210	2 030 to 2 159
Soil texture	Sandy loam	Loam	Sandy loam	Loam	Sandy loam
Parent material	Volcanic	Volcanic	Shallow calcareous	Shallow calcareous	Shallow calcareous
Dominant sagebrush type	*Artemisia tridentata* Nutt. subsp. *wyomingensis* Beetle & Young	*Artemisia nova* A. Nelson	*Artemisia tridentata* Nutt. subsp. *wyomingensis* Beetle & Young	*Artemisia nova* A. Nelson	*Artemisia tridentata* Nutt. subsp. *vaseyana* (Rydb.) Beetle

They concluded that an unintended consequence of mechanical treatments using chaining and seeding of perennial grasses was future dominance of Utah juniper at the expense of two-needle pinyon.

Life history traits of singleleaf pinyon pine (*Pinus monophylla* Torr. & Frém.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little) suggest that each species responds to and recovers from disturbance in a different fashion. Juniper exhibits greater resistance than pinyon to most disturbances, exhibiting higher survivorship following fire, drought, and insect outbreaks (Tausch and West 1988; Mueller et al. 2005; Greenwood and Weisberg 2008). Due to relatively high stem flexibility, juniper also experiences lower mortality than pinyon pine from mechanical disturbance such as chaining (Tausch 1973). Juniper is also less dependent than pinyon pine upon favorable microsites and biotic facilitation from nurse shrubs (Callaway et al. 1996; Chambers 2001). Following fire, juniper generally establishes within the first 5–55 yr and pinyon arrives later, particularly once a shrub layer has developed (Barney and Frischknecht 1974; Everett and Ward 1984; Tausch and West 1988; Bauer 2006). However, presence of slash piles or large woody debris may also provide biotic safe sites for pinyon and juniper seedlings, as has been observed to accelerate the rate of postfire establishment for other pine species (Castro et al. 2011).

Chaining produces an environment with unique conditions for tree seedling survival that differ greatly from conditions created by natural disturbances in the Great Basin. The first few years following chaining have reduced availability of biotic safe sites because the treatment causes high shrub mortality (Tausch 1973; Redmond et al. 2013). Natural Great Basin disturbances such as drought, tree disease, and insect attack do not affect the shrub layer as severely, although wildfire can result in nearly complete mortality or top-kill of the shrub community. Tree establishment following treatment may also be limited by competition from surviving trees and from perennial grasses that are commonly seeded following chaining or prescribed burn treatments. Surviving trees may also indirectly reduce tree establishment by outcompeting and excluding shrubs, which are potential safe sites for trees (Callaway et al. 1996).

We explored whether differential effects of chaining and prescribed fire treatments on site environment have consequences on species-specific establishment rates and eventual species composition of the stand. We used tree-ring analysis to evaluate effects of treatment on density and relative dominance of establishing singleleaf pinyon (hence "pinyon") and Utah juniper (hence "juniper") trees 33 yr after burning on five prescribed fires in one location and 39 yr to 50 yr after chaining at four locations. We also compared tree densities in 2008 with densities observed from an earlier posttreatment sampling in 1971 to compare changing tree density increases of the two species following chaining or burning. We hypothesized that because chaining treatments leave a more suitable environment for tree germination and early seedling survival, chaining treatments will experience more rapid rates of tree establishment than burning treatments. We further hypothesized that greater juniper establishment would occur at burned sites, whereas greater pinyon establishment would occur at chained sites because pinyon depends more heavily on safe sites and facilitation.

METHODS

Study Area

The five study sites are located in several mountain ranges that are oriented in a north–south direction along the eastern side of Nevada. Gradual slopes of mostly open woodlands with understory mosaics of sagebrush shrubs and perennial bunchgrasses characterize the area. All five sites experience similar levels of mean annual precipitation (340–397 mm) but vary in temperature regime, dominant sagebrush type, and underlying parent material (Table 1). The oldest and southernmost chaining treatment is the Blythe Springs Chaining, located on the west side of the Delamar Mountains in south-central Lincoln County, Nevada. In March 1958, approximately 500 ha were chained one way with a 28 $kg \cdot m^{-1}$ smooth chain and seeded to crested wheatgrass (*Agropyron cristatum* [L.] *Gaertn*) the next fall. In 1985, 78% of the site was chained a second time. After the second treatment, the site was seeded to antelope bitterbrush (*Purshia tridentata* [Pursh] *DC*.), fourwing saltbush (*Atriplex canescens* [Pursh] Nutt.), clover (*Trifolium* L. sp.), alfalfa (*Medicago sativa* L.), intermediate wheatgrass (*Thinopyrum intermedium* [Host] Barkworth & D.R. Dewey), and crested wheatgrass. Mean cover of herbaceous species was only approximately 1% in both years of sampling, 1971 and 2008 (Bristow 2010). Single-chained and double-chained portions of the site could not be reliably distinguished and were combined in our data analysis.

Spruce Mountain, the northernmost of the chainings, is located in Elko County, Nevada near the Pequop Mountains. The Spruce Mountain chaining (late fall 1962) treated approximately 1 100 ha by chaining one way with an 83 $kg \cdot m^{-1}$ smooth chain drawn by two D-8 Caterpillar tractors, and was not reseeded. Mean herbaceous understory cover declined from 4.4% in 1971 to 1.3% in 2008 (Bristow 2010). Soils on the southwestern side of Spruce Mountain are primarily volcanic and receive from 305 $mm \cdot yr^{-1}$ to 381 $mm \cdot yr^{-1}$ of precipitation (Tausch 1973). About 96 km south and 48 km east of Spruce Mountain are the Kern Mountain chainings, which are located in northeastern White Pine County, Nevada. The North Kern East Chaining (October 1969) is on the north side of the Kern Mountains and at this location about 160 ha were double-chained using the Ely Chain with seeding between chainings. (The Ely Chain is a large ship's anchor chain with railroad iron welded to each link, leading to considerable soil reworking and scarification that facilitates subsequent reseeding.) The South Kern Chaining (October 1968) is on the south-central base of Kern Mountain and directly across the valley from the north end of the North Snake Range. Here 200 ha were double-chained using the Ely chain with seeding between chainings. The Kern Mountain chainings were seeded with a mixture of shrubs, grasses, and forbs, but primarily crested and intermediate wheatgrass. Mean cover of herbaceous species declined between 1971 and 2008 from 5.6% to 3.1% at South Kern, and from 2.3% to 1.4% at North Kern (Bristow 2010).

Since treatment, all chained sites have likely experienced moderate levels of cattle grazing during summer. Blythe Springs and Spruce Mountain are used by deer primarily in winter, whereas the Kern Mountain chainings experience year-round use, but with heaviest browse utilization in spring and fall (Tausch 1973).

The five prescribed fire sites that were resampled are located on the east side of the White Pine Range, southwest of Ely, Nevada (Ward 1977, Everett and Ward 1984). All five were burned during spring or early summer of 1975, resulting in near 100% mortality (Ward 1977). The areas treated range from 5 ha to 12 ha, and were not reseeded. The burned sites have been used as summer range for cattle grazing under moderate stocking rates since the 1960s, but were not grazed for several years following the burns (Everett and Ward 1984).

Data Collection

Both treatments were first sampled between 1 yr and 13 yr after implementation. Although various environmental and vegetation attributes were measured, only information on posttreatment tree density is reported here. Chaining treatments were sampled for vegetation recovery and deer utilization by Tausch (1973), who used a stratified random sampling technique for distributing plots within sites to capture variation in slope, aspect, elevation, and soil type. At treatment and control plots, tree density and cover were measured for each tree in two 0.08-ha subplots on randomly located transects. Plot locations were marked using fence posts and rebar and relocated to carry out the current study.

In 1975 and 1976, Ward (1977) performed a vegetation succession study following five small (5-ha to 12-ha) prescribed burns. The sampling design consisted of systematically orienting 30-m transects from randomly located starting points within each of the five prescribed burns. Plant species cover and density data were collected in 15 evenly spaced, 30×60 cm subplots along the 30-m transects. After treatment, Ward (1977) found no live trees present for measuring. Plot locations were marked using fence posts and rebar and relocated to implement the current study.

At each site location originally sampled by Tausch in 1971 (Tausch 1973) or Ward in 1976 (Ward 1977), every 0.08-ha plot originally sampled (range: 1–11, depending on treatment area) was resampled for tree density, cover and age. At each plot, diameter data were collected from every tree species and age data were taken from a random subsample of 24 trees. Trees with basal diameters larger than 8 cm were cored as close as possible to the root collar using an increment borer. At least two cores were taken for each tree. Measurements of coring height above root collar and trunk diameter at coring height were recorded for each sample collected. For trees smaller than 8 cm in basal diameter, a cross section was removed just above the root collar.

Increment core or cross-sectional samples were processed using standard dendrochronological techniques after sanding using progressively finer grits of sandpaper until tracheids were clearly visible (Stokes and Smiley 1968). Tree ages were adjusted for coring height above root collar using an empirical age–height relationship developed from a destructive sampling of pinyon seedlings and saplings (Bauer and Weisberg 2009):

$$\text{Age correction} = 24.60 + 0.218 \cdot \text{CH}\,(\text{cm}) \qquad [\mathbf{1}]$$

where CH is coring height. Age adjustments for cores that miss tree pith used an empirical relationship based on early growth response of singleleaf pinyon, after estimating distance to pith using the concentric circle method (Applequist 1958; Bauer 2006). Three researchers independently counted and cross-checked every sample, and all discrepancies were resolved by recounting until a consensus was reached regarding tree age. Dendrochronological cross-dating was not possible due to low variability in radial increment and relatively short tree-ring chronologies. Therefore, dates of establishment for tree cores taken from older, larger trees lacked annual precision, but most discrepancies between independent ring counts were within 3 yr. Dates of establishment were more likely annually precise for younger, smaller trees from which cross sections were taken.

Data Analysis

Age structures of the 0.08-ha plots were examined using frequency histograms aggregated to 1-yr and 5-yr bins. Mean rates of pinyon and juniper tree establishment ($trees \cdot ha^{-1} \cdot yr^{-1}$) were compared between chaining and burning treatment types. Fixed effects analysis of variance was used to determine if tree establishment rates for both species combined, and each species separately, were significantly different ($\alpha \leq 0.05$) between treatments. Because trees were not cored in control plots, stand basal diameter size structures were compared between treatment and control plots, instead of tree ages. Changes in tree density between 1971 and 2008 were also examined for control and treated plots.

RESULTS

Relative rates of tree establishment differed among treatment types ($F_{1,7}=5.5$, $P=0.051$) (Table 2). Over both species, almost

Table 2. Mean number of trees established per hectare per year following chaining ($n=4$ in "Chaining" column) and prescribed fire ($n=5$ in "Fire" column) treatments. Standard errors (SE), mean difference between treatment types, and *P*-values from fixed-effects analysis of variance comparing means of the two treatment types are also shown.

Tree species	Chaining (mean trees · ha $^{-1}$ · yr $^{-1}$ ± SE)	Fire (mean trees · ha $^{-1}$ · yr $^{-1}$ ± SE)	Difference	*P* value
Combined	5.86 ± 1.56	2.06 ± 0.77	3.81	0.05
Pinyon	3.90 ± 1.21	0.62 ± 0.29	3.29	0.02
Juniper	1.96 ± 0.47	1.44 ± 0.57	0.52	0.52

four more trees per hectare per year established following chaining than following fire. This effect was primarily due to pinyon, whereas juniper establishment did not differ significantly among treatments (Table 2).

There was site-specific variation in the relative frequency of trees having established before treatment and surviving, or having established following treatment (Fig. 1). One site (Blythe Springs), which had the lowest density of trees establishing pretreatment, had been chained twice. For the other chained sites, from 1.5 times to 5 times as many trees had established prior to treatment and survived, as established following treatment (Fig. 1). No trees survived the burned treatment at the White Pine site.

Relatively high rates of tree establishment occurred immediately following treatment at all chained sites. Juniper establishment was high in the first 10–20 yr but diminished with time (Fig. 2). For the four sites that were chained only once, pinyon establishment began to exceed juniper establishment within approximately 15–25 yr after chaining (Fig. 3). The only site that was chained twice (Blythe Springs) had relatively few surviving trees that established soon after the first chaining, likely due to the effects of the second chaining. Following the second chaining at Blythe Springs there was a small surge of establishment that quickly dropped to low levels within the next 15 yr (Fig. 2).

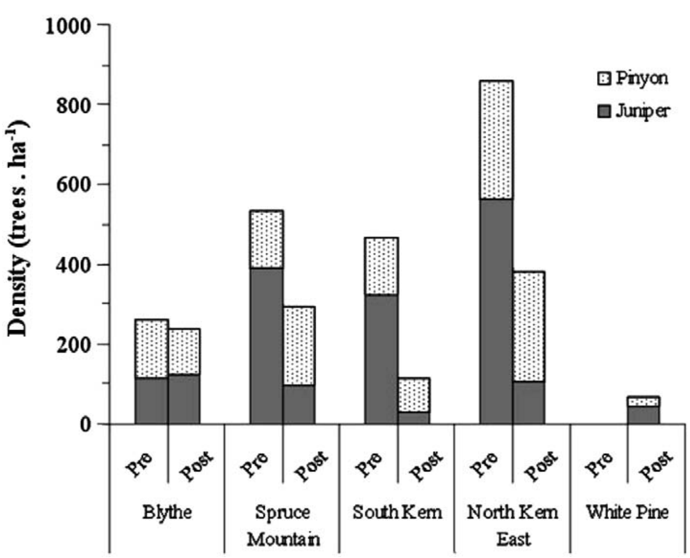

Figure 1. Densities of pinyon (*Pinus monophylla*) and juniper (*Juniperus osteosperma*) trees establishing before and surviving treatment (left: pretreatment) and establishing after treatment (right: posttreatment) for five sites in eastern Nevada. Chained sites include Blythe Springs, Spruce Mountain, South Kern, and North Kern East. The White Pine site was treated with prescribed fire.

In contrast, pinyon establishment has been minimal at the White Pine prescribed fire sites. Establishment of pinyon remained relatively constant and quite low for the first 25 yr before stopping completely at approximately year 2000. Establishment of juniper on the prescribed burn was initially four times as great as that of pinyon, but also declined over time and ceased by year 2000 (Fig. 2).

At most sites in both treatment and control plots, pinyon and juniper density increased between original sampling in 1971 and resampling in 2008 (Fig. 4). At all sites, increases in control plot tree densities exceeded increases in treatment plot density. With the exception of the twice-chained Blythe Springs site, the species composition of trees establishing between 1971 and 2008 in the control plots roughly paralleled that of the chained sites (Fig. 4).

DISCUSSION

Tree Establishment Rate

Treatment effects contributing to much greater tree establishment after chaining than after prescribed fire can be understood in terms of underlying mechanisms of tree regeneration ecology, including seed availability, safe site availability, seed dispersal, and seed predation. Chained sites likely had greater availability of nurse plants that benefit pinyon and juniper seedling establishment. Treatment differences with respect to seed dispersal and seed predation are less easily quantified and depend upon differential behavior of granivorous bird and mammal species with respect to recently chained and burned habitats (e.g., Vander Wall 1997; Vander Wall and Balda 1977).

Greater availability of pinyon and juniper seed from both within and outside the treatment areas may have led to greater tree establishment at chained sites than at prescribed fire sites. Some trees that survived chaining treatment had recovered sufficiently to produce seed before 2008, whereas burned sites remained completely devoid of seed-producing trees (Fig. 1). On-site seed-producing trees of both species likely contributed to greater tree establishment at chained sites than at prescribed fire sites.

Pinyon and juniper rely heavily on seed-caching birds and rodents for seed dispersal and deposition of seed at necessary soil depths for germination (Vander Wall 1997; Vander Wall and Balda 1977). However, seed dispersal was likely not limiting for even the larger chained sites. Birds, which disperse a majority of pinyon and juniper seed, can travel as far as 5–10 km to cache seed (Chambers et al. 1999). The interiors of all

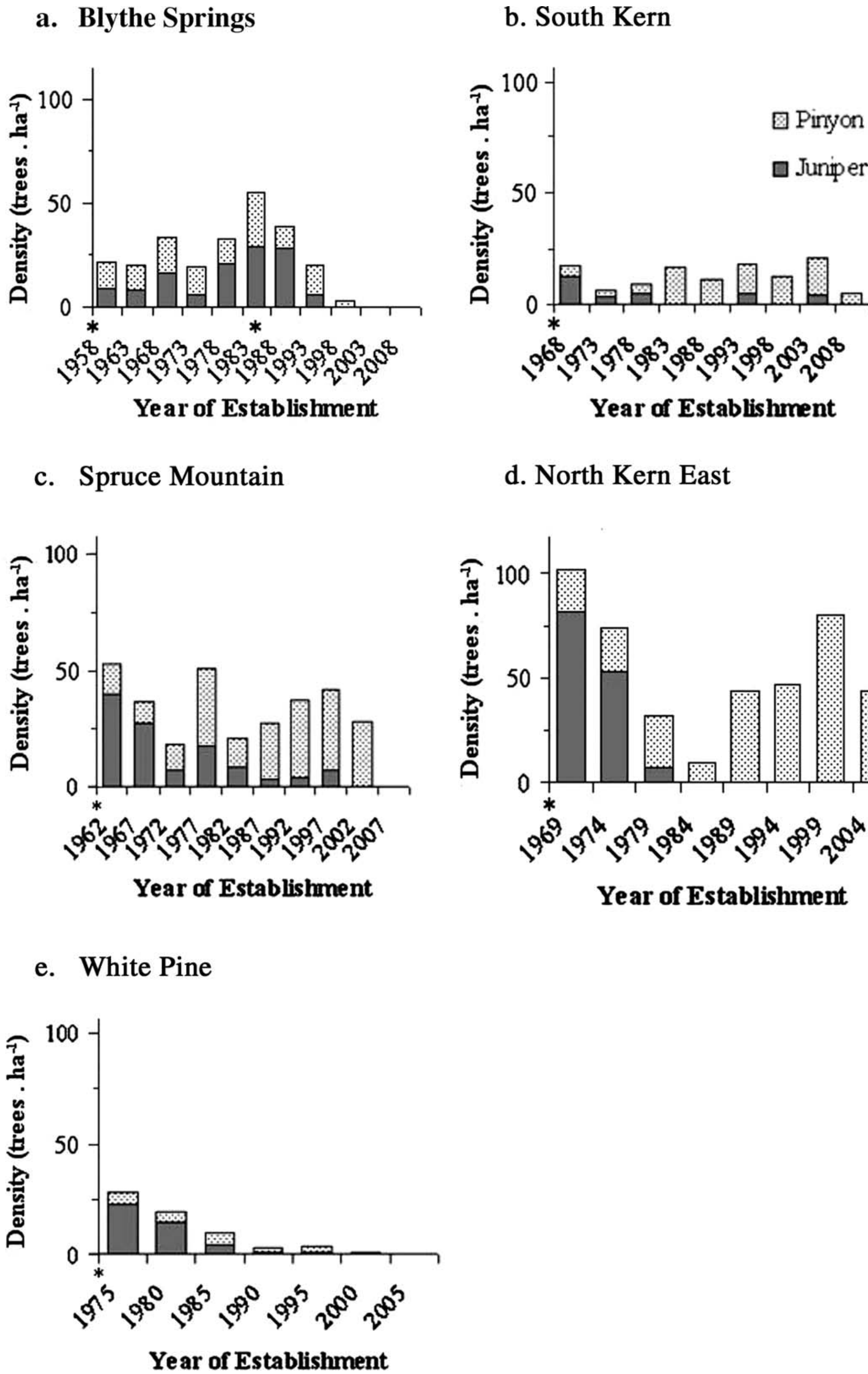

Figure 2. Frequency distributions of establishment years for pinyon (*Pinus monophylla*) and juniper (*Juniperus osteosperma*) trees establishing after treatment for five sites in eastern Nevada. Chained sites include **a,** Blythe Springs; **b,** Spruce Mountain; **c,** South Kern; and **d,** North Kern East. **e,** The White Pine site was treated with prescribed fire. Bars represent 5-yr bins of establishment years and asterisk symbols represent years of treatments.

treatments studied were well within 5 km of the treatment perimeter.

Availability of nurse plants, or structural equivalents for providing suitable microsites, was likely an important factor influencing tree establishment rate on prescribed burns and chained sites. Nurse shrubs, usually big sagebrush (*Artemisia tridentata* Nutt.), favor the establishment of both tree species but are essential for successful pinyon establishment (Chambers

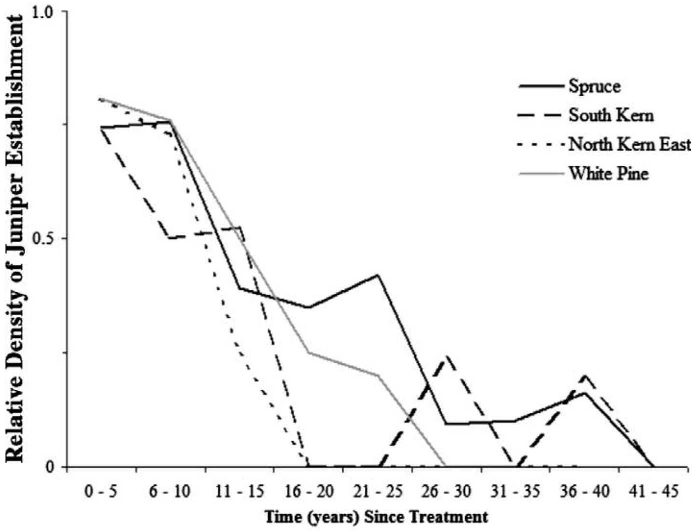

Figure 3. Emergence of juniper relative to pinyon over time, binned by 5-yr increments.

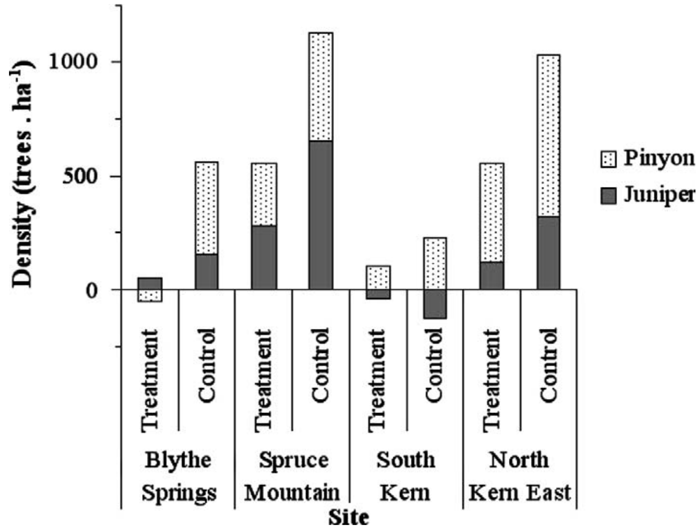

Figure 4. Changes in density of pinyon and juniper trees for treated and control sites between 1971 and 2008.

et al. 1999), particularly on drier sites (Ziffer-Berger et al. 2014). Following both chaining and burning, biotic safe sites are reduced because sagebrush, which is the primary nurse plant for Great Basin trees (Callaway et al. 1996), also experiences mortality (Tausch 1973). However, following chaining, slash piles composed of coarse woody debris can replace biotic safe sites. Slash piles vary in size and composition, but may provide shading, cooling, and moisture necessary for seedling germination and survival. At prescribed burn sites in our study, few shrubs existed initially to provide suitable safe sites, slash piles were not present, and any tree seedlings that could establish were likely subjected to intense competition from high herbaceous plant cover. Thus, lack of safe site availability could explain the observed differences in tree establishment rate between the treatments.

Differences in chronology of tree establishment at burned and chained sites will have lasting effects on plant community composition. Tree establishment at burned sites was low immediately following treatment, then dropped further over the next 15 yr and stabilized near zero for the last 18 yr prior to sampling (Fig. 2). Observed increases in tree density at burned sites were minor in comparison with the sustained density increases observed at chaining treatments. Continued establishment of trees at chained sites will result in more rapid stand closure and loss of understory species (Tausch et al. 1981; Miller et al. 2000). Understory plant species can persist for a longer duration at burned sites, where initial tree density is low and further tree establishment has been drastically reduced.

Although chaining appears to create a more suitable environment for tree establishment than burning, untreated sites experienced the highest level of new tree establishment. The greatest tree density increases were observed in control plots (Fig. 4). With respect to the management goal of reducing further tree establishment relative to untreated areas, some success was achieved with chaining treatments but prescribed burning was more successful.

Relative Establishment Rates of Pinyon and Juniper

Greater establishment of pinyon at chained sites and juniper at prescribed fire sites may be attributed partly to safe site requirements of the pinyon pine (Tausch and West 1988; Callaway et al. 1996; Chambers et al. 1999). Juniper established in similar densities at burned and chained sites, which is consistent with the ability of juniper to establish despite absence of nurse shrubs (Chambers et al. 1999). Pinyon established in greater quantities at chained sites, where a variety of slash material and recovering shrubs provided shading.

Differences in chronologies of tree species establishment at treated sites indicated that juniper was more capable than pinyon of early establishment on the treated sites studied. Species-specific differences in reproductive life history traits may have been responsible for observed differences. Juniper seed remains viable for up to several years, whereas pinyon seed viability decreases after 1 yr (Johnsen 1959; Chambers et al. 1999). Viable seed in the seed bank may have been important for juniper establishment for the first few years after chaining, when proximity to mature trees with seed was initially reduced.

Composition of soil fungal mycorrhizal communities is another factor that can affect available soil moisture for tree seedlings and potentially prevent earlier colonization by pinyon pine (Haskins and Gehrig 2005). Pinyon forms associations with ectomycorrhizal (EM) fungi, but juniper and most other Great Basin plant species are hosts of arbuscular mycorrhizal fungi. EM inoculation of germinating pinyon roots occurs six times less frequently in juniper-dominated zones than in pinyon-dominated zones, and extent of root inoculation is reduced (Haskins and Gehrig 2004). Without other species of plants providing EM reservoirs, pinyon roots are less likely to be inoculated (Haskins and Gehrig 2004; Hubert and Gehrig 2008).

Availability of EM can be affected by prescribed fire and chaining treatments. High tree mortality and intense heat from fire can reduce EM availability for pinyon seedling root inoculation (Neary et al. 1999; Swaty et al. 2004; Hart et al.

2005; Hubert and Gehrig 2008). The potential role of mycorrhizal community composition for influencing species composition of establishing trees following disturbance requires further research.

IMPLICATIONS

This study was retrospective and not set up as a controlled comparison experiment, limiting our inferential ability to compare among different treatments and environmental conditions. However, observed differences between chained and burned sites were dramatic. Results demonstrate that chained sites can be rapidly recolonized by trees and achieve pretreatment densities within a few decades, whereas the prescribed burn treatment we resampled proved resistant to tree invasion over a multidecadal period. That juniper establishment has been more recently replaced by pinyon establishment at chained sites has implications for future woodland structure, assuming that sites are not retreated. At the site of a mid-19th century wildfire, Tausch and West (1988) reported that pinyon establishment did not exceed juniper establishment until 60 yr following burning. Pinyon establishment at the prescribed fire sites used for this study had not begun to increase by 2008, 33 yr after burning. However, pinyon establishment exceeded that of juniper after about 15 yr at chained sites in this study, indicating that pinyon might become the dominant species sooner following chaining than following fire. The timeframe required for pinyon dominance likely depends upon site productivity and effectiveness of postchaining treatments such as reseeding. Redmond et al. (2013) observed that Utah juniper continued to be more dominant than pinyon pine (*Pinus edulis*) within 20–40 yr after chaining, leading to an opposite conclusion than ours concerning influences of chaining treatments on relative tree dominance. However, their study area in Utah's Grand Staircase–Escalante National Monument was drier than any of our sites (251 mm mean annual precipitation, 1960–2010), which would generally favor juniper over pinyon pine. It also experienced effective reseeding and stronger effects of chaining on reducing subsequent tree establishment than were observed in our study, where reseeding was relatively ineffective (Tausch and Tueller 1977).

Results of this study highlight the need and usefulness of long-term monitoring of treatment sites. Had sites only been sampled within 15 yr of treatment, there would have been evidence of only juniper trees reestablishing at all sites (Fig. 2). Sampling multiple decades after treatment captures changes in tree population structure that will affect long-term composition and structure of woodlands. Chaining treatments without follow-up retreatment will not only be rapidly recolonized by trees, but have potential to create or amplify landscape-level shifts in tree species composition. Immediate effects of the chainings we studied included differential tree species mortality, with juniper survivorship exceeding pinyon survivorship, causing initial juniper stand dominance. By 15 yr following chaining, the establishment of pinyon trees had exceeded juniper, suggesting eventual future dominance by pinyon. Pinyon pine can reestablish on chained sites much faster than on burned sites. The decision to treat pinyon and juniper woodlands mechanically, by prescribed fire, or by leaving untreated requires a long-term perspective incorporating expected responses of treatment on eventual tree population processes.

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