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Long-term effects of chaining treatments on vegetation structure in piñon–juniper woodlands of the Colorado Plateau

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ABSTRACT

Over the last half-century a range of methods have been utilized to reduce trees and shrubs in order to reduce wildfire risk and promote herbaceous vegetation to support livestock and wildlife. We examined the long-term (20–40 year) effects of past tree-reduction treatments on vegetation and ground cover in piñon–juniper woodlands, which is the third most extensive vegetation type in the continental United States. Tree-reduction treatments were conducted between 1963 and 1988 in Grand Staircase-Escalante National Monument, Utah by the US Bureau of Land Management and involved chaining followed by seeding to remove trees and often shrubs. Treatments were effective at increasing perennial grass cover and reducing tree cover over multiple decades. The increase in perennial grass cover was predominantly due to a nonnative species that was seeded, *Agropyron cristatum* (crested wheatgrass). Surface fuel loads were nearly twice as high in treated areas, likely changing fire behavior and increasing habitat complexity. Treated areas had higher bare mineral soil cover and lower biocrust cover, which may influence soil erosional processes. Interestingly, treated areas had significantly less *Pinus edulis* (piñon pine) recruitment compared to untreated areas, while there was no change in *Juniperus osteosperma* (Utah juniper) recruitment. These results indicate that treated areas may become more *J. osteosperma* dominated in the future due to increased establishment of *J. osteosperma* compared to *P. edulis*. Our results show that while treatments were effective at reducing tree cover and increasing herbaceous cover, there were long-term (40 year) treatment effects on vegetation composition and ground cover that need to be taken under consideration when developing future management strategies.

1. Introduction

Across the western US, there is an increasing need to effectively manage ecosystems to both mitigate hazardous wildfires and maintain, and in some cases restore, the structure, function, diversity and dynamics of forest and rangeland ecosystems. Of particular importance to the management of public lands in the western US are ecosystems dominated by various species of piñon (e.g., *Pinus edulis and P. monophylla*) and juniper (e.g., *Juniperus monosperma*, *J. osteosperma*, and *J. occidentalis*), which collectively represent the third most extensive vegetation type in the continental US and are one of the predominant vegetation types administered by federal land-management agencies in the US (Romme et al., 2009).

During the past half-century, piñon–juniper (P–J) ecosystems have been a major focus for land-management activities due to their great spatial extent, the multiple ecosystem services they provide, and historic changes in the structure and extent of P–J populations. Across the western US, P–J populations have established in adjacent grassland and shrubsteppe vegetation, and existing woodlands have experienced increased tree recruitment and stand densities over the last century (Barger et al., 2009; Miller and Rose, 1999; Miller et al., 2008; Tausch et al., 1981). In thickening woodlands and where trees have established in adjacent grasslands and shrubsteppe, competition from trees has contributed to declines in forage production for livestock and diminished habitat quality for some wildlife species (Bates et al., 2005; Clary and Jameson, 1981; Noson et al., 2006). In some settings, increasing tree dominance and decreasing herbaceous cover have contributed to increases in runoff and soil erosion (Wilcox, 1994), with implications for long-term ecosystem sustainability.

Thus, since the 1950s a variety of tree-reduction methods have been used across large tracts of public lands in the western US in attempts to restore herbaceous cover and production. These early treatment methods, which predominantly involved green chaining and seeding, were effective at increasing herbaceous cover (Aro, 1971; Tausch and Tueller, 1977) and, in certain cases, reducing runoff and soil erosion in the short-term (Farmer et al., 1999;

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Gifford, 1973). However, the effectiveness of these treatments at maintaining low tree densities, high herbaceous cover, and reducing soil erosion in the long-term are largely unknown (but see Pierson et al., 2007 and Skousen et al., 1989).

Despite this lack of knowledge, concern over threats posed by wildland fire over the last decade has led to sharp increases in the number and extent of new tree-reduction projects, some of which use the same chaining techniques common in the 1960s. Many of these projects have been conducted in conjunction with the US National Fire Plan, which aims to reduce the risk of catastrophic wildland fire while restoring ecological functions to forests and woodlands across the US. Whereas past management treatments primarily focused on forage production for livestock, managers are now tasked with treating for multiple objectives, including fire prevention and maintenance of ecosystem attributes such as soil stability and fertility, hydrologic processes, and ecosystem resistance to invasion by exotic plants. Thus, there is a clear need for understanding the longer-term effects of tree-reduction on vegetation structure and soil properties in these ecosystems.

In this study, we examined how past chaining treatments influenced plant communities and soil surface characteristics at 17 paired (treated vs. untreated) sites that were chained and seeded between 1963 and 1988. We also examined whether vegetation and soil surface responses changed as time since chaining treatment increased (from 18 to 43 years). We predicted that these past chaining treatments would lead to increased herbaceous cover and decreased tree cover. Additionally, we hypothesized that as time since chaining treatment increased there would be an increase in tree cover leading to a decline in herbaceous cover. We focused our study in Grand Staircase-Escalante National Monument located in southern Utah on the Colorado Plateau, where numerous chaining treatments have occurred (http://www.mpcer.nau.edu/pj/pjwood/).

2. Materials and methods

2.1. Study area and treatment methods

From May thru August 2006, we sampled 17 paired (treated vs. untreated) sites located within P–J woodlands in Grand Staircase-Escalante National Monument, Utah that had been treated between 1963 and 1988 by the Bureau of Land Management (BLM) (see Table 1 and Fig. 1). For our treated sites, we focused on tree-reduction treatments involving chaining and seeding (Table 1), as those were the most common treatment methods used by the BLM and were applied to over 169,000 ha of land across the Colorado Plateau since the 1940s (http://www.mpcer.nau.edu/pj/pjwood/). The chaining treatment method involves two tractors pulling heavy chains (18–40 kg/link) in a "U" or "J" shaped pattern to pull over and uproot trees and often shrubs (BLM, 2008). Smooth chains were used at all sites except for site 126 where Ely chaining was used. An Ely chain had short pieces of hardened railroad rails welded perpendicular to each link to increase soil disturbance and uproot more trees and shrubs. Both smooth and Ely chaining disturb soils, and in all of the treatments examined in this study, plant debris was left in the treatment to reduce erosion (BLM, 2008). All treatments involved seeding, however, the seeding methods and species mixes seeded into the area varied (see Table 1 for details). Seeding was done either using aerial or hand broadcasting, where seeds are left on the soil surface, or by drilling or using a dribbler, where equipment is used to bury seeds (BLM, 2008). While all treatments involved chaining and seeding, the combination of treatment methods varied (Table 1). For example, some sites were double chained and then seeded (denoted as chain/chain/seed in Table 1) while other sites were chained once and then plowed and seeded (denoted as chain/plow/seed in Table 1). All paired untreated sites were adjacent to the treatment area and of similar slope (±9°), aspect (±75°), elevation (±75 m) and of the same soil map unit (Natural Resource Conservation Service, 2006).

Sites were located in either persistent P–J woodlands or wooded shrublands (Romme et al., 2009), with vegetation consisting of overstory *P.edulis* Engel. (twoneedle piñon) and *J. osteosperma* (Torr.) Little (Utah juniper). All paired sites had at least one tree with a basal trunk diameter greater than 22 cm, suggesting that trees had established prior to the 20th century at our study sites (Despain, 1989; Barger et al., 2009). The dominant shrub in the area is big sagebrush (*Artemesia tridentata* Nutt. and *A.tridentata* Nutt. ssp. *tridentata*), which ranged from 0 to 35% cover in the untreated sites. Other shrub species common at many of the sites included broom snakeweed (*Gutierrezia sarothrae* (Pursh) Britt. and Rusby), Mormon tea (*Ephedra viridis* Coville), and antelope bitterbrush (*Purshia tridentata* (Pursh) DC.).

Table 1
Treatment year, treatment method, species seeded, amount seeded (in parenthesis next to species seeded in kg ha^{-1}), method of seeding for all treated sites, and mean slope, aspect, and elevation for each paired site at Grand Staircase-Escalante National Monument, Utah. The order in which treatment combinations were applied is denoted by slashes with methods in chronological order (i.e. Chain/Plow/Seed indicates the site was chained, then plowed, then seeded).

Paired site	Slope	Aspect	Elev. (m)	Year treated	Treatment method	Species seeded	Seeding method
137	2°	S	1960	1963	Chain/Seed	*A. cristatum* (7.8)	Drill
139	2°	E	2027	1964	Chain/Windrow/Seed	*A. cristatum* (6.7)	Drill
127	1°	W	1840	1965	Plow/Chain/Seed	*A. cristatum* (6.7)	Aerial Broadcast
129	1°	E	1960	1965	Chain/Chain/Seed	*A. cristatum* (6.7)	Aerial Broadcast
130	4°	S	1973	1965	Chain/Chain/Seed	*A. cristatum* (6.7)	Aerial Broadcast
133	3°	SE	1604	1965	Chain/Chain/Seed	*A. cristatum* (6.7)	Aerial Broadcast & Drill
135	5°	SE	2148	1965	Chain/Seed	*A. cristatum* (6.7)	Aerial Broadcast
110	2°	SE	1886	1966	Chain/Seed/Chain	*A. cristatum* (6.7)	Aerial Broadcast
131	4°	S	2002	1966	Chain/Chain/Seed	*A. cristatum* (6.7)	Aerial Broadcast
132	5°	E	2042	1968	Chain/Plow/Seed	*Elymus junceus* (5.6)	Aerial Broadcast
134	3°	SE	1762	1969	Chain/Chain/Seed	*A. cristatum* (5.6), *Atriplex cansecens* (0.3), *Medicago sp.* (5.6), *Purshia tridentata* (0.3)	Aerial Broadcast
113	5°	SE	1950	1971	Chain/Seed/Seed	*A. intermedium* (5.8)	Aerial Broadcast
150	5°	SW	1892	1981	Chain/Chain/Seed	*A. cristatum* (4.5), *A. trichophorum* (2.2), *E. junceus* (3.4), *Meliotus officinalis* (1.1), *P. tridentata* (0.3)	Aerial Broadcast
126	1°	S	2028	1982	Chain/Plow/Seed	*Other Herbs* (7.1)	Aerial or Hand Broadcast
128	6°	SW	2192	1982	Chain/Seed	*A. cristatum* (9.0), *E. junceus* (6.7), *A. intermedium* (2.2), *M. officinalis* (2.2), *A. cansecens* (0.3)	Aerial Broadcast & Dribbler
107	2°	E	2036	1983	Chain/Seed	*A. cristatum* (4.5), *A.trichophorum* (3.4), *M. offiinalis* (0.9), *Onobrychis sp.* (0.9)	Aerial Broadcast
123	1°	E	1859	1988	Chain/Seed	*A. cristatum, E. junceus*	Drill