15 Reversing the Woodland Steady State: Vegetation Responses During Restoration of *Juniperus*-Dominated Grasslands with Chaining and Fire

R. James Ansley and Harold T. Wiedemann

Introduction

Junipers (*Juniperus* spp.) are native woody shrubs that have expanded beyond their normal historical ranges in the western and southwestern United States since the late 1800s (Johnson 1962; Burkhardt and Tisdale 1976; Gehring and Bragg 1992; Ansley et al. 1995; Miller and Tausch 2001; Ueckert et al. 2001). The most likely reason for this is the change in the disturbance regimes associated with these communities and the lengthening of the time between disturbances that removed juniper. Increases in juniper can be attributed to fire suppression, climate change, and overgrazing by livestock. Overgrazing had the dual effect of weakening the competitive ability of grasses against emerging juniper seedlings and reducing the amount of herbaceous fine fuel that normally supported fires (Archer et al. 1995; Van Auken 2000).

Junipers have encroached upon 8.8 million ha of rangeland in Texas and 1.4 million ha in Oklahoma and negatively influenced land use (SCS 1983, 1988; Snook 1985). Increases in density and distribution of these species has increased remarkably in the last 50 to 60 years. For example, from 1948 to 1982, redberry juniper (*Juniperus pinchotii* Sudw.) distribution in northwest Texas increased from 2.5 to 4 million ha, or 61% (Ansley et al. 1995). Distribution of eastern redcedar (*Juniperus virginiana* L.) and Ashe juniper (*Juniperus ashei* Buchholz) in Oklahoma has increased from 1.4 to 2.4 million ha, or 71%, during the short period of 1985 to 1994 (McNeill 2000).

The Woodland Steady State

Junipers threaten grassland ecosystems through a steady encroachment and ultimate domination (Bragg and Hulbert 1976; Tausch et al. 1981; Ansley and Rasmussen 2005). This change is largely a function of a consistent pattern of seed dispersal and a favorable competitive environment for emerging juniper seedlings. Juniper seedling survival is often increased when the herbaceous layer is overgrazed by livestock.

O.W. Van Auken (ed.), *Western North American Juniperus Communities: A Dynamic Vegetation Type.*

Once a certain threshold of woody encroachment into grasslands is reached, normal graminoid-driven succession patterns give way to a shrub-driven succession, as illustrated by Archer (1990). Succession patterns among herbaceous species become modified by the shrub effect. Moreover, the presence of a woody overstory may modify wildlife migration patterns, such that the potential for changes in wildlife-mediated seed dispersal patterns increases, and this may add to shrub-driven succession through the introduction of new plant species into the ecosystem.

Woody plant dominance in grasslands is often considered a "woodland steady state" because the system will not likely shift back to grassland without anthropogenic manipulation of the woody vegetation (i.e., fire, mechanical, chemical), especially if the dominant woody species can sprout from the subterranean meristem following destruction of aboveground tissue. Examples are redberry juniper and honey mesquite (*Prosopis glandulosa*). Juniper species in general provide one of the more robust examples of how woody species maintain a steady state, and the probability of juniper woodlands naturally crossing the threshold and reverting back to an intermediate shrub-steppe or to grassland is very low in the absence of a major disturbance or costly anthropogenic inputs (Miller et al. 2000).

Juniper Effects on Herbaceous Production

Several studies have quantified the competitive effects of individual juniper trees on herbaceous growth and have documented a progressive increase in herbaceous production with increasing lateral distance from an individual juniper tree (Engle et al. 1987; Dye et al. 1995). Shading caused by evergreen foliage and the dense canopy structure of junipers prevents herbaceous vegetation from growing beneath the canopy. The lateral root system can cause extreme soil drought conditions at the canopy dripline and just beyond. It appears from these studies, however, that the lateral roots of individual junipers do not exert much of an effect on herbaceous production beyond 2 m from the dripline in redberry juniper (Dye et al. 1995), or 1 m beyond the dripline in eastern redcedar (Engle et al. 1987). These studies suggest the lateral root system of junipers is more restricted to the immediate environment of the juniper canopy, in contrast to honey mesquite, which has an extensive lateral root system.

Most community-level studies indicate that the functional relationship between percent juniper canopy cover (or density) and herbaceous production (or cover) follows either a negative linear or a negative exponential function (Jameson 1967; Clary 1971, 1987; McPherson and Wright 1990; Miller et al. 2000). These relationships are fairly consistent across a variety of juniper species and ecosystems, although the amplitude of this relationship changes with precipitation patterns and site (McPherson and Wright 1990). A common response in all these studies is that herbaceous production declines significantly with as little as 10% to 20% of juniper canopy cover, which appears to be somewhat inconsistent with the individual tree studies described above. If the competitive influence of single juniper trees was restricted to 1 to 2 m beyond the dripline, then one would not expect to see such a sharp decline in herbaceous production at relatively low juniper cover values. Clearly, there are synergistic effects among juniper trees that occur at the community level that are not well understood; these are no doubt a function of the size of the individual juniper trees.

Many other studies, although not focused on quantifying a functional relationship between juniper cover and herbaceous production, have demonstrated an increase in herbaceous production following juniper removal. Increases in herbaceous plant production are often substantial the first few years after treatment, even doubling or tripling that of pretreatment levels (Arnold 1964; Clary 1971; Steuter and Wright 1983). However, little is known about what factors are involved and how they interact to affect herbaceous recovery. Certainly, condition of the herbaceous community before treatment, soil health (amount of A and B horizon remaining; soil organic matter content, etc.), and posttreatment precipitation patterns are important. Because juniper domination tends to increase the amount of bare ground in addition to reducing growth of existing herbaceous patches, posttreatment recovery is also dependent on the rate of recruitment of herbaceous plants into bare soil areas (Miller et al. 2000). If the herbaceous community is dominated by bunchgrasses, then recruitment must come from seed. In the Intermountain region of Nevada and Utah, because of lower rainfall and generally more shallow soils, unaided rates of recovery are often too slow and seeding of herbaceous species is required.

Junipers and Herbaceous Composition

Posttreatment vegetation composition and succession trajectories following juniper control can be highly variable (Tausch et al. 1993). Postfire succession models presented by Barney and Frischknecht (1974) and Everett and Ward (1984) portray a progression from annuals to perennial grasses to grass/shrub mix to juniper dominance over time. In these models, juniper encroachment gradually gains over time. In the case of a resprouting species such as redberry juniper, a postfire increase to the point of dominance would be expected to occur much earlier (perhaps within 20 years) than that expected with juniper species, which depend on seedling recruitment. Annual forbs in this model would increase rapidly in the immediate postfire years (Koniak 1985) and may increase later as annual grasses and/or forbs when juniper is dominant. As juniper begins to dominate, the diversity of herbaceous species will likely decline.

The succession models portrayed by Barney and Frischknecht (1974), West and Van Pelt (1987), and others may still apply toward much of the southern prairie of Oklahoma and Texas where perennial grasses remain dominant. However, in many areas of the Intermountain region, the increase in annual grasses such as cheatgrass (*Bromus tectorum*) has largely altered this basic succession model by replacing the intermediate seral stages (i.e., perennial grass, shrub-steppe/grass mix) with an annual grass-dominated phase that has potential for high fire frequency. If true, Miller and Tausch (2001) suggest these communities may have difficulty returning to perennial grass or juniper woodland stages. In these regions, annual grasses may become a more important concern than reducing juniper stands with fire. Cool season (C_3) annual grasses have increased in many areas of the southern Great Plains, and it is worth considering that these may also have the potential to alter succession patterns in juniper woodlands (Ansley et al. 2004).

Restoration of Juniper-Dominated Grasslands

Numerous efforts have been made to return juniper-dominated areas to grasslands. Much of the motivation for earlier restoration efforts was to increase grass production for livestock grazing (Clary 1971; Steuter and Wright 1983). Although this remains an important consideration, there are other reasons for juniper control in addition to or in lieu of increasing livestock production. Juniper domination reduces habitat for wildlife species, particularly grassland birds that depend on open spaces (Belsky 1996). Moreover, juniper domination can cause increases in bare ground and severe soil erosion and can mine soil nutrients from interstitial spaces (Schlesinger et al. 1990; Davenport et al. 1998). The presence of a closed canopy stand of juniper also creates the potential for a catastrophic summer season crown fire that may threaten property. Thus, in many areas of the southern Great Plains there may be adequate justification for anthropogenically shifting the woodland steady state back to grasslands. It is acknowledged that certain woodland obligate species such as the golden-cheeked warbler (*Dendroica chrysoparia*) and black-capped vireo (*Vireo atricapillus*) are trigger points for the argument against juniper reduction. Perhaps the basis for decisions should focus more on the conservation of the soils resource than other factors (Davenport et al. 1998). The potential for long-term soil erosion is high in closed-canopy juniper areas that have had a crown fire disturbance because of the high amount of bare soil and slow herbaceous recovery rates.

Fire Disturbance Regimes

The consensus of opinion remains that many areas in the Great Plains and Intermountain region were once grasslands that have become dominated by junipers (Steuter and Britton 1983; Burkhardt and Tisdale 1976; Miller and Tausch 2001). Pre-settlement fire return interval was less than 10 years for much of the Great Plains and 12 to 25 years in the Intermountain region (Frost 1998;

Miller and Tausch 2001). Grassland communities in the Great Plains had more frequent fires than the Intermountain region because of an even distribution of readily combustible fuel (grass) and a greater frequency of ignition potential from lightning strikes or native Indian activities than that found in the Intermountain region. The lengthening of the fire return intervals associated with settlement by Europeans in the late 1800s likely stimulated juniper encroachment.

A fire return interval less than 10 years may have been key toward preventing encroachment by resprouting juniper species such as redberry juniper. Fire-induced mortality of redberry juniper was 90% when trees were less than 0.16 m tall but 37% in plants 0.16 to 0.34 m tall (Steuter and Britton 1983). With a growth rate of 0.04 m/year, redberry juniper plants that were less than 0.16 m tall were assumed to be 4 years old or younger. Thus, 4- to 8-year-old plants were twice more resistant to fire than younger plants, presumably because the basal bud zone began to be covered with soil and was protected from fire. Smith et al. (1975) found that redberry juniper survived ground-level clipping of all stems when plants were about 8 years of age. Resistance to aboveground disturbances is a function of the rate at which the basal caudex became covered with soil (McPherson and Wright 1989). The species sprouts from this meristem if aboveground tissue is killed. Thus, if pre-settlement fire frequency was less than 10 years in the southern Great Plains, it is likely that most seedling and juvenile redberry juniper plants were killed by wildfires before they became fire resistant.

Other juniper species in the Great Plains such as eastern redcedar and Ashe juniper can be killed by fire because they will not resprout following destruction of aboveground tissue (Wink and Wright 1973). However, size plays a role, and complete aboveground mortality achieved by fire declines considerably when trees are more than 2 m tall (Dalrymple 1969; Martin and Crosby 1955; Owensby et al. 1973). Moreover, these species have a net effect of lengthening the fire return interval because of their competitive effects on herbaceous production.

Prescribed Fire in Combination with Other Treatments

Prescribed burning has been used to accelerate the fire return interval in juniper-dominated grassland ecosystems and restore herbaceous dominance (Wright and Bailey 1982; Steuter and Britton 1983; Rasmussen and Wright 1989). Most prescribed fires in the southern Great Plains have been conducted during winter months. As a single treatment, winter fires are most effective when juniper encroachment is in early stages when juniper size and densities are low and the ecosystem is still primarily herbaceous. However, because of the influence of juniper on herbaceous production, it is difficult to send a fire through stands of mature junipers because of the lack of herbaceous fuel between juniper canopies. Because of this, moderate to dense stands of junipers are often mechanically treated to reduce juniper competition and increase the herbaceous growth that fuels a subsequent fire (Wink and Wright 1973; Rasmussen et al. 1986; Ansley and Rasmussen 2005). Another alternative is to burn under conditions when fire intensity is high enough to generate a crown fire, thus bypassing the need for herbaceous fuel links between juniper plants (Bryant et al. 1983). Research into the potential of summer season fires is currently underway at several locations. For the time being, however, this chapter focuses on the mechanical + fire treatment option.

A common mechanical treatment is chaining, in which trees are felled by an anchor chain pulled between crawler tractors (Fisher et al. 1973). Typically, chaining costs about \$30 to \$45 ha^{-1} (\$12–\$18 ac^{-1})(Johnson et al. 1999), but in dense stands of large junipers on rocky sites, chaining can be much more expensive because of greater resistance to pulling. Wiedemann and Cross (1996) determined that an elevated chaining technique could reduce pulling requirements of individual trees by 84% in redberry junipers and 67% in Ashe juniper while maintaining tree felling efficacy similar to that of ground-level chaining. The elevated chain, suspended 0.6 m above ground through the use of a rotating ball attached to the chain midway between the two tractors, will partly uproot juniper trees exposing the bud zone and potentially increase plant mortality by using fire to destroy the exposed bud zone. In theory, a ground level chain scrapes across the soil surface and has a greater chance of damaging herbaceous plants and soil crusts and increasing bare ground and the potential for soil erosion than does an elevated chain. In addition, the elevated chain is less likely to spread unwanted species such as prickly pear cactus (*Opuntia* spp.) than is a ground level chain. Thus, from a herbaceous restoration standpoint, an elevated chain may achieve the desired result on juniper yet have a less drastic effect on the herbaceous community and accelerate the restoration process over that of a ground level chain.

Many studies have observed vegetative responses of juniper to fire alone or chaining alone (Clary 1971; Tausch and Tueller 1977; Steuter and Britton 1983; Rippel et al. 1983; Barnitz et al. 1990), but few have quantified effects of combined mechanical + fire treatments on dense juniper stands over a long enough period to measure responses after each treatment. Recently, Johnson et al. (1999) determined in an economic modeling study that chaining followed by burning in 7-year intervals was an economical method of redberry juniper control in north Texas. Increased livestock production (cattle) in response to increased herbaceous production was used as the basis to calculate net present values of the investment in brush control treatments over a 30-year period. However, these projections were not based on quantified herbaceous responses to chaining + fire. Relatively few studies in the southern Great Plains have actually quantified ecosystem responses to mechanical treatment of juniper followed by a maintenance fire, and none of these monitored responses on the same site for more than 2 years (Wink and Wright 1973; Steuter and Wright 1983; Rasmussen and Wright 1989). Thus, there is a need for quantification of long-term effects of such combined treatments for juniper control.

A New Study: Combined Effects of Chaining and Fire

Scientists at the Texas Agricultural Experiment Station in Vernon, Texas, have recently completed a study to determine the potential of chaining followed by prescribed fire on restoration of a badly degraded site in north Texas dominated by redberry juniper (see Ansley et al. 2006). Specifically, the study quantified the effect of two types of chaining (ground-level and elevated), each followed by fire 4 years later, on juniper canopy reduction and mortality, herbaceous production by functional group (C_3 vs. C_4), herbaceous composition, bare ground, and litter cover. Another objective of the study, not documented here (see Wiedemann et al. 2006), was to quantify effects of these treatments on populations of the horse fly (*Tabanus abactor* Philip, also known as the "cedar fly"), a pest to livestock in juniper-dominated rangeland. The remainder of this chapter reports results from this study.

Study Area and Treatments

The study occurred on two sites in the Rolling Plains ecological region of northwest Texas (Johnson: 33°59' N, 99°50' W; Halsell: 33°50' N, 99°48' W). Soils at both sites were complexes of the Cottonwood (silt loam; thermic Lithic Ustorthents), Talpa (loam; thermic Lithic Calciustolls), and Knoco (clay loam; thermic shallow Aridic Ustorthents) soil series (NRCS office, Vernon, TX). Mean annual precipitation is 616 mm, most occurring between April and October (NOAA 2003). Herbaceous vegetation at both ranch locations is dominated by C_4 (warm season) perennial grasses, including sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), little bluestem (Schizachyrium scoparium), tobosagrass (*Hilaria mutica* (Buckl.] Benth), buffalograss (*Buchloe dactyloides* (Nutt.] Engelm.), silver bluestem (*Bothroichloa laguroides* (DC.) Herter. spp. *torreyana* (Steud.), and red threeawn (*Aristida purpurea*). Also present is the C_3 (cool season) perennial Texas wintergrass (*Nassella leucotricha* Trin. and Rupr.). There are numerous forb species, but none occurs in great quantities.

The study had three treatments with four replicate plots per treatment. Plot size ranged from 12 to 17 ha. Treatments were (1) untreated control, (2) ground level chaining followed by fire 4 years later (GLC + F), and (3) elevated chaining followed by fire 4 years later (EC + F). A dense stand of redberry juniper (>30% cover) occurred in each plot before treatments.

Chaining was conducted in March 1997 when adequate soil moisture was present. Two crawler tractors, pulled 54-m of 52-mm-diameter anchor chain (12.4 kg/link or 58.4 kg/m) for ground-level chaining. For the elevated chaining treatment, a spherical ball, 1.2 m in diameter, was fabricated from 13-mm steel plate and attached midway in the chain. The chain was thus suspended between the ball and the two crawlers such that the average striking height of the chain was 0.6 m above ground (for more details, see Wiedemann and Cross 1996).

Fires were applied as head fires in February and early March 2001, 4 years after the chaining treatments, following guidelines by White and Hanselka (1991). Plots were burned as individual units with a total of eight plots burned (four at each site). Fire intensity was moderate because droughts in 1998, 2000, and 2001 had the cumulative effect of lowering fuel moisture content and limiting fine fuel accumulation.

Timing of the fire treatment at 4 years after chaining mimicked a typical situation for such a combined treatment management scenario (Rasmussen and Wright 1989). It is usually too hazardous to burn downed juniper within the first 2 years of felling by chaining because of highly volatile fuels and the potential for fire brands to travel great distances.

Juniper Responses

Both chaining treatments reduced juniper canopy cover to less than 1% and juniper tree height from 2.8 m to less than 1.0 m. By 2003, 2 years after the fire treatments were imposed, juniper regrowth had increased canopy cover in the GLC + F and EC + F treatments to 4% and 6%, respectively, which were both significantly different from the control (see Figure 1). Juniper canopy cover increased in the untreated control from 30% to 51% (1996 to 2003).

Juniper mortality in 1997 at 8 months postchaining averaged 20% for both methods of chaining. However, by 2003, 6 years postchaining and 2 years after the fire treatment, mortalities were 8% and 4% in SC + F and EC + F treatments, respectively. We hypothesized that the fire treatment 4 years after chaining would increase

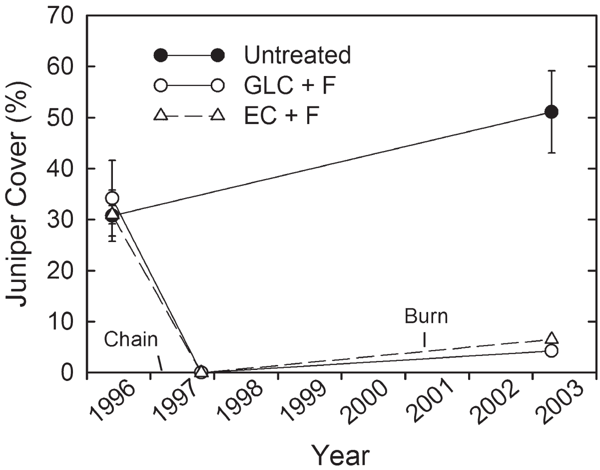

Figure 1 Redberry juniper canopy cover in response to the three treatments: *untreated*, *GLC + F*, standard chain + fire; *EC + F*, elevated chain + fire). *Vertical bars* are ±1 standard error (SE) (from Ansley et al. 2006)

juniper mortality over that of chaining alone by killing exposed meristem on trees that had been partly uprooted. Thus, the reduction in juniper mortality from 1997 to 2003 was unexpected. Some uprooted stumps that were counted as dead in 1997 may have sprouted between 1997 and 2003, thus lowering the mortality percentage. In addition, herbaceous fuel remained patchy at the time of burning, and an even flame front was not achieved. Areas that were initially dense, closed-canopy patches of juniper likely did not have sufficient growth of herbaceous fuel between 1997 and 2001 for fire to have an effect on the chained junipers.

The low juniper mortality rates contributed to the observation of no net change in juniper densities during the course of the study. Although the chaining + fire treatments did not reduce juniper density, they did reduce tree height and canopy cover such that the competitive effect of juniper was greatly reduced.

Precipitation

Annual precipitation was above the long-term average in 4 years (1997, 1999, 2000, and 2002) (Figure 2). Drought conditions prevailed in 1996, 1998, 2001, and 2003. Droughts in 1998 and 2001 were especially severe with very little precipitation occurring during the growing season. Precipitation patterns were similar between the Halsell and Johnson sites.

Herbaceous Standing Crop

End-of-growing-season grass standing crop ranged from 20 to 120 g m^{-2} throughout the study (see Figure 2). Pretreatment standing crop, collected in April 1996, was near 70 g m^{-2} in all treatments. In the year following chaining treatments, standing crop decreased to a greater degree relative to pretreatment levels in the standard chain treatment than in the other treatments, probably because of the scraping effects of standard chaining on the soil surface. The 1998 drought reduced grass standing crop in all three treatments, but the decline was most severe in the control.

Grass standing crop did not increase in treated plots over the control until 1999, four growing seasons after chaining. At this point, standing crop in both chaining treatments was similar and about twice that of the control. These differences between treatments continued into the next year, although standing crop in the ground level chain treatment was slightly greater than in the elevated treatment. Both remained significantly greater than the control.

After fire treatments were imposed in early 2001, grass standing crop declined in both chain + fire treatments. Standing crop also declined in the control treatment, probably because of the drought in this year. Thus, standing crop reductions in the chain + fire treatments may have been caused by the combined effects of fire followed by drought. However, because the rate of decline was similar in all three

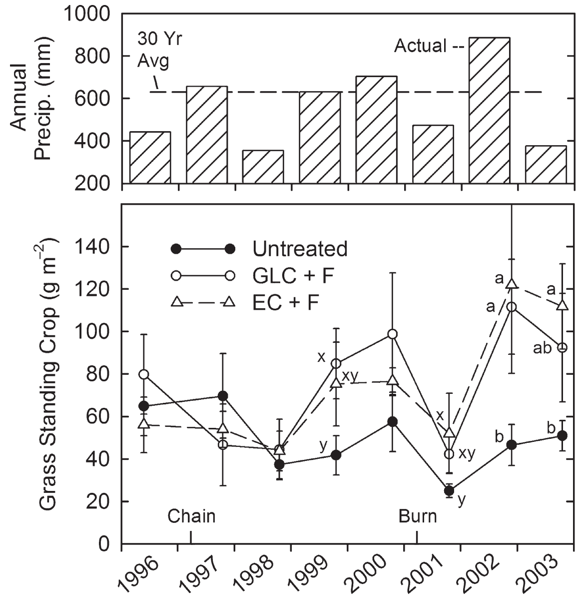

Figure 2 Annual precipitation and 30-year mean annual precipitation at the site (*top*) and end-of-growing-season grass standing crop (live + dead) in response to the three treatments (*bottom*). Treatment codes: *GLC + F*, standard chain + fire; *EC + F*, elevated chain + fire. *Letters within a sample date* that are different indicate a significant difference at $P > 0.05$; any sample dates without letters indicates no significant differences among treatments (from Ansley et al. 2006)

treatments, we may assume that drought was more responsible than fire in explaining the reduction in grass standing crop in the treated plots.

Grass standing crop in treated plots increased to two to three times that in the untreated control the second and third year after fire. A peak standing crop of 110–120 g m^{-2} occurred in 2002, an above-normal precipitation year. There was no difference in standing crop between standard and elevated chaining treatments after 2000. In the control, grass standing crop declined gradually over the course of the study but declined most notably in the drought years of 1998 and 2001.

End-of-season standing crop of all perennial grass functional groups (C_3 perennial grasses, C_4 midgrasses, C_4 shortgrasses) indicated a general trend toward decreasing in the control and either increasing or remaining unchanged in the treated plots, but there were no statistically significant differences (data not shown). Significant differences in standing crop between treatments were only found when these functional groups were treated collectively.

A positive linear relationship occurred between annual precipitation and end-of-growing-season grass standing crop during posttreatment years of 1998–2002 (Figure 3). The slope of the relationship was much steeper in treated plots that had less than 5% *Juniperus* cover than in the untreated control, which had 40% to 50% *Juniperus* cover during this time period.

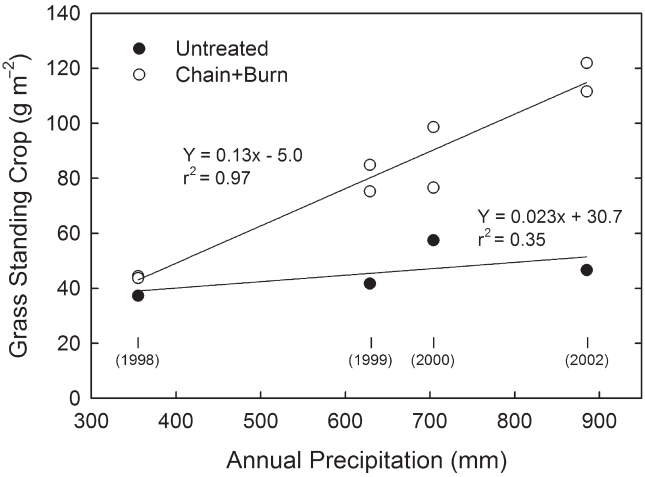

Figure 3 Regression between annual precipitation and end-of-growing season grass standing crop in treated (*open circles*) and untreated (*closed circles*) rangeland from 1998–2002. Each *point* represents the mean of a treatment. Data from the SC + F and EC + F treatments were grouped into the "chain + fire" treatment. Juniper cover was 40%–50% in the control plots and >5% in the treated plots (from Ansley et al. 2006)

End-of-growing-season forb standing crop was low in all treatments throughout the study, ranging from 0.4 to 14 g m^{-2} (data not shown). Forb standing crop was similar among all three treatments except in 1999, 2002, and 2003 when it was greater in the treated plots than the control. The fire treatment in 2001 appeared to increase forb standing crop.

Few studies in the region have quantified long-term herbaceous production following the combined treatments of chaining and burning of juniper woodlands. Wink and Wright (1973), in a study in which juniper was dozed in 1965 and burned in 1970, found that grass production was 131 g m^{-2} in untreated controls and 185 g m^{-2} in dozed + burned plots the first growing season post fire. Grass data were collected only in that year. Steuter and Wright (1983), in a study where juniper was chained in 1974 or 1975 and burned in 1979, found first-year postfire grass production was 61 g m^{-2} in untreated plots and 75 g m^{-2} in chained + fire plots. Again, only first-year postburn data were collected. In our study, increases in grass biomass did not occur until the second growing season post fire and these were more than twice that in the control. We know of no studies that have quantified grass responses under a combined treatment scenario for as many years as the current study.

Herbaceous Cover Responses

Total grass cover was lower in treated plots relative to the control immediately after chaining, but this difference disappeared by 1998 (Figure 4). Total grass cover did

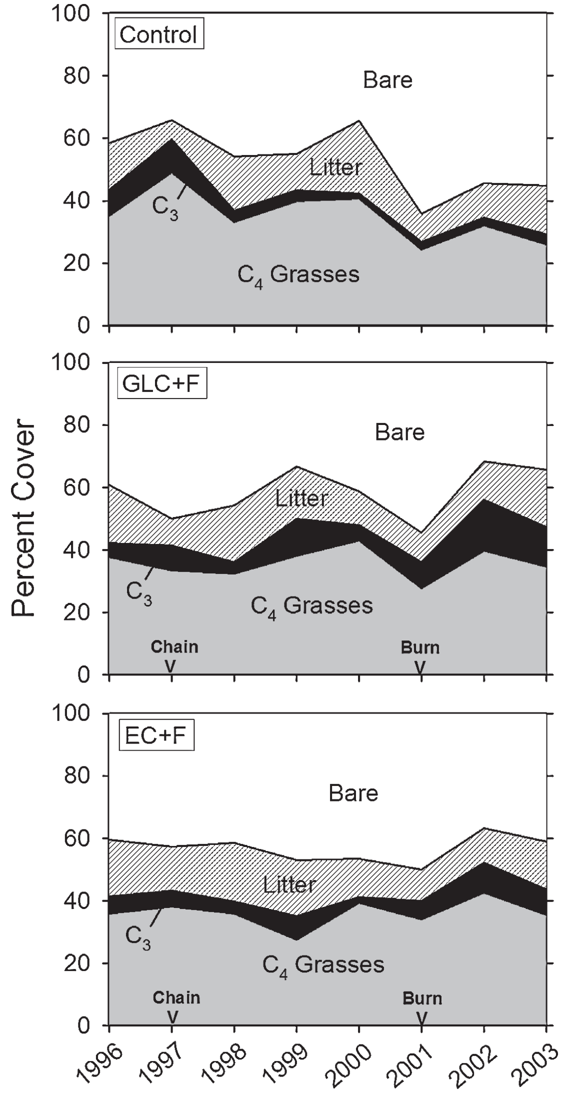

Figure 4 Total grass foliar (C_3 and C_4) cover and percent bare ground in response to chaining and fire treatments. Treatment codes: *GLC + F*, standard chain + fire; *EC + F*, elevated chain + fire

not increase in treated plots over the control until after the fire treatment. This response differs from that found with grass standing crop, which was greater in chained treatments than the control for 2 years before burning. These results suggest that increases in grass standing crop from chaining alone (in 1999 and 2000) were caused by increased growth of existing grass patches. The fire treatment may have stimulated recruitment of grass species into bare soil areas and, as such, postfire increases in grass standing crop in 2002 and 2003 were probably a combination of increased growth in existing grass patches plus increased recruitment into bare soil areas. Above-normal precipitation in 2002 also may have contributed to the accelerated growth and/or recruitment into bare soil areas.

Bare ground was near 40% in all treatments at study initiation and did not change much between treatments over the course of the study until the severe drought in 2001 (see Figure 4). At this time, bare ground in the control plots increased from 35% to 65% and remained above 55% in 2002–2003. In the treated plots, bare ground remained fairly constant from 1996 to 2001, with a slight but not significant increase from fall 2000 to fall 2001 in response to the spring 2001 fire. In the second and third growing seasons following fire (2002 and 2003), bare ground in both the GLC + F and EC + F treatments decreased from about 50% to between 30% and 40%. Thus, although 4 years of drought during an 8-year period ultimately increased bare ground in juniper woodlands, percent bare ground remained unchanged or slightly decreased in the chaining + fire treatments. We expected bare ground area to significantly decrease in the treated plots over 8 years, but in a community largely dominated by C_4 bunchgrasses, any reduction in bare ground would need to come from recruitment of new plants via seed. The droughts may have prevented this from happening.

Forb cover remained less than 4% in all treatments (data not shown). Forb cover showed a trend of being greater in treated plots than the control, especially after the fire treatments, but these differences were not significant.

Herbaceous Composition

Changes in cover of all herbaceous functional groups during the period of the study are shown in Figure 4. The immediate impression from this figure is that treatments did not alter composition at the functional group level much beyond that which was found in the untreated control. However, some subtle differences were apparent. C_4 grasses slightly declined in the control while they remained unchanged or slightly increased in the treated plots. The C_3 grasses and forbs, shown collectively in Figure 4, increased slightly in the treated plots and slightly decreased in the control. As mentioned before, bare ground increased in the control, while it remained unchanged or was slightly decreased in treated plots. Litter cover was similar in all treatments, remaining about 10% to 20% of the total cover. These responses, when viewed collectively, suggest that the treated sites were moving toward a greater herbaceous domination. Total herbaceous cover increased to nearly 50% in treated plots compared to 30% in the control by study's end.

There were no clear differences in species composition responses between the GLC + F and EC + F treatments during the study, with the possible exception that, for reasons unknown, responses were less variable from year to year in the EC + F treatments than in the GLC + F treatment. This observation may relate to the greater degree of soil disturbance that was assumed (not quantified) to occur as a result of ground-level chaining in the GLC + F treatment, but the mechanism as to how this caused greater variability in composition from year to year is unknown.

Postfire succession models developed in the Intermountain region by Barney and Frischknecht (1974), Everett and Ward (1984), and West and van Pelt (1987) portray a progression from annuals to perennial grasses to grass/shrub mix to juniper dominance over time. In these models, annual forbs increase rapidly in the immediate postfire years (Koniak 1985). Juniper encroachment gradually gains over time and, as juniper begins to dominate, herbaceous species diversity and perennial grass production decline. In the case of a resprouting species such as redberry juniper, a postfire increase to the point of dominance would be expected to occur much earlier (perhaps within 20 years) than that expected with juniper species that depend on seedling recruitment.

Results from the current study do not lend support to these models, however, as we did not find a strong shift toward forbs in the first few years post fire. Although there was a slight increase in C_3 grasses and forbs in the burned plots in 2002 and 2003, 2 and 3 years after the fire, species composition remained dominated by C_4 grasses and bare ground. It should be noted that, because we monitored postfire responses for only 3 years, we have no basis to compare our study with the projected intermediate succession stages in the Barney and Frischknecht (1974) model.

Ecological and Management Implications

Combined treatments of mechanical chaining followed by repeated fires will likely accelerate the restoration process of juniper-dominated rangelands (Ansley and Rasmussen 2005). In Ashe juniper communities, a single mechanical treatment allowed juniper to significantly recover within 15 years, whereas the same treatment followed by fire 5 years later minimized juniper recovery. Prescribed fire altered the successional pattern to a more diverse shrub and herbaceous community (Rasmussen and Wright 1989).

Figure 5 illustrates hypothetical long-term ecological responses to three management scenarios applied to a mature juniper stand: using mechanical treatments alone, prescribed fire alone, or an initial mechanical treatment followed by repeated fire treatments. If a mechanical treatment such as chaining was used alone, it probably would not be applied more frequently than every 40 years due to prohibitive costs. Such a treatment scenario probably would not keep pace with the overall deleterious effects of increasing juniper encroachment. Both peak perennial grass production as well as juniper production would likely gradually decline over time due to soil loss during the periods of juniper domination (Figure 5). Fire, because of lower cost, could be applied more frequently than mechanical treatments, shown in Fig. 5 at every 20 years, but would not be as effective initially as a mechanical on reducing mature juniper cover and density. After several burns, fire may gradually reduce the peak to

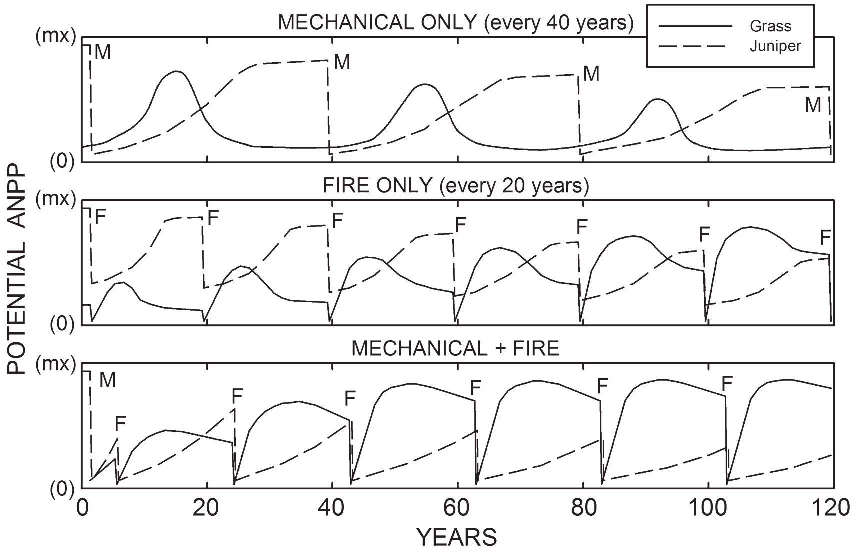

Figure 5 Potential ANPP (annual net primary productivity) of grass (*solid line*) and juniper (*dashed line)* over 120 years in each of the three treatments: mechanical (*M*) only, fire (*F*) only, and mechanical + fire (*mx*, maximum) (from Ansley and Rasmussen 2005)

which juniper production could recover. Moreover, assuming a constant precipitation pattern, repeated fires would likely gradually increase both peak production and duration high production of grasses, but it might take a century and 6 or 7 fires to ultimately shift the balance to grass dominance. In contrast, if an initial high-cost mechanical treatment were followed with fire 4–5 years after mechanical and then at 20 year intervals, juniper dominance might be avoided indefinitely and perennial grass production would more rapidly increase to a sustained maximuim. These scenarios are all based on the assumption that high cost seeding is not part of the treatment plan.

Data from Ansley et al. (2006) suggest that complete restoration of juniper-dominated regions, even under a combined treatment scenario, may not occur rapidly on badly degraded sites; hence we show in the bottom panel of Figure 5 a slow herbaceous recovery in the first 20 years. Condition of the resource before treatment and weather conditions following treatment are key variables in determining rates of restoration (Everett and Ward 1984; Tausch and Tueller 1977).

Although grass biomass and cover increases in the treated plots were not as great as hypothesized, one revealing element of this study was the observation of the progressive impacts of juniper domination on the herbaceous community. During the droughts of 1998 and 2001, herbaceous production declined sharply. Coupled with this, the herbaceous community was not able to make significant gains during wet years, as responses in the control in 1997, 1999, and especially 2002, revealed. A long-term pattern of herbaceous species losing ground in drought years and failing to recover in wet years suggests a trend toward degradation. These responses imply that a "do-nothing" custodial management of juniper-dominated rangelands in the southern prairie may not be an acceptable option.

Summary

Juniper (*Juniperus* spp.) encroachment in grasslands usually progresses toward a woodland "steady state" of mature trees that requires a significant disturbance to shift succession in another direction. Fire alone is often inadequate and must be preceded by a mechanical treatment such as chaining to reduce juniper competition and increase herbaceous growth that fuels a subsequent fire. The objective of this study was to quantify the potential of chaining followed by fire on restoration of a badly degraded site in north Texas dominated by redberry juniper (*J. pinchotii*). Chaining was conducted in 1997 and fires were applied in March 2001. Treated areas (chaining + fire) were compared to untreated controls (four plots per treatment). Livestock grazing was excluded. Juniper cover was reduced to less than 5%, but mortality was less than 15% as most plants basal sprouted. Herbaceous production did not increase in treated plots over the control until 3 years after chaining. Production declined in all treatments the first growing season following fire but increased in treated plots to three times the control the second and third year after fire. Total grass cover in treated plots did not increase over the control until the second year after fire treatment. Results suggest herbaceous production increases from chaining alone were caused by increased growth of existing vegetation patches. The fire treatment appeared to stimulate herbaceous recruitment into bare soil areas.

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