A Demonstration Project to Test Ecological Restoration of a Pinyon-Juniper Ecosystem

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Abstract—*To test an approach for restoring historical stand densities and increasing plant species diversity of a pinyon-juniper ecosystem, we implemented a demonstration project at two sites (CR and GP) on the Grand Canyon-Parashant National Monument in northern Arizona. Historical records indicated that livestock grazing was intensive on the sites beginning in the late 1800s and continuing through the mid 1900s. Repeat aerial photographs (1940 and 1992) indicated recent increases in stand density and encroachment of trees into formerly open areas. Age distributions indicated that the majority of pinyon trees at both sites were less than 100 years of age and juniper establishment appeared to peak in the late 1800s to early 1900s, although some junipers had establishment dates as early as 1700-1725. Pretreatment understory communities were sparse (< 7% total herbaceous cover) as were seedling densities in seed banks (151 seedlings per m^2 (14 seedlings per ft^2) at CR and 192 seedlings per m^2 (18 seedlings per ft^2) at GP). Before experimental treatments were implemented, a bark beetle outbreak at GP resulted in >50% pinyon mortality, which was positively related to tree size and age. The demonstration treatment consisted of thinning small trees (< 25 cm diameter at root collar (DRC)), lopping and scattering thinned trees, and seeding native understory species. Thinning and mortality reduced overstory density from 638 and 832 trees per hectare pretreatment (258 and 337 trees per acre) to 280 and 251 trees per hectare (113 and 102 per acre) posttreatment at CR and GP, respectively. Posttreatment densities were similar to those suggested for the late 1800s by dendrochronological stand reconstructions. Thinning small diameter pinyon increased residual quadratic mean diameter (QMD) at CR and the relative importance of juniper at both sites. Live canopy fuels were reduced by treatment at CR and by thinning plus beetle-related mortality at GP. Although thinning slash was lopped and scattered, woody surface fuels were not significantly different between treated and control units at either site, perhaps due to the small size of thinned trees and the large interspace areas into which slash was scattered. Treatment had no immediate effects on herbaceous cover or species richness, both of which may take more time to develop. Further monitoring will help to clearly evaluate the effectiveness of this treatment for satisfying restoration and conservation goals.*

Introduction

In this paper, we report preliminary results of an ecological restoration demonstration project we are conducting at two pinyon-juniper sites in northern Arizona. The project was initiated as a response to ecosystem health concerns described for pinyon-juniper woodlands of the Southwest. On many pinyon-juniper sites, recent ecological changes include decreased diversity of grasses and forbs, decreased biotic and genetic diversity, introduction of exotic species, increased soil erosion,

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and decreased site productivity (Dahms and Geils 1997, West 1999, Hastings and others 2003). Many of these deleterious effects appear to be linked to intensive livestock grazing, exclusion of naturally occurring fire, and striking increases in tree density commencing in the late 1800s with the arrival of EuroAmerican settlers and industrial land use practices (Burkhardt and Tisdale 1976, Young and Evans 1981, West 1999, Miller and Tausch 2001). One possible solution for improving ecosystem health and sustainability is ecological restoration.

Several papers dealing with ecological restoration are presented in this proceedings and a brief discussion of definitions is warranted. The Society for Ecological Restoration defines restoration as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER 2002). Although this definition implies reparation of an identifiable ecosystem (i.e., not creation of an entirely new system), it does not tell us how to balance strict focus on historical patterns with uncertainty about those patterns and our desires for improved site conditions. Some scholars contend that "good" restoration must represent both an attempt to reestablish ecological integrity as well as a specific focus on addressing social values and concerns (Higgs 1997). Other basic principles of restoration include the following: a) identify and halt causes of degradation; b) set goals for recovery; c) establish monitoring programs, measures of success, and adaptive processes; and d) plan for the long-term. Finally, all principles must be embedded within a collaborative framework. In this demonstration project, we endeavored to restore historical ecosystem characteristics as well as initiate the development of future conditions desired by land managers.

Study Area

We identified two sites for study on Grand Canyon-Parashant National Monument near Mount Trumbull, Arizona (fig. 1). The Craig Ranch site (CR) is located at latitude 36N 26' 01" and longitude 113W 09' 40". The Goose Ponds (GP) site is located at latitude 36N 24' 46", and longitude 113W 12' 15". Elevation of the sites ranges from approximately 1900 m to 1950 m (6270-6435 ft) (fig. 1). Precipitation averages approximately 50 cm (19.7 in) annually and falls during distinct winter and summer periods. Soils at the CR site are shallow to deep gravelly sandy loams to very cobbly clays derived from limestone, basalt, and sandstone alluvium and colluvium. Those at the GP site are shallow to very deep, very cindery loams derived from alluvial and colluvial, scoriaceous basalt and pyroclastics (USDA Soil Conservation Service 1993, 1995a,b). Vegetation at the sites is classified as Great Basin Cold Temperature Woodland (Brown 1994). Overstories are all-aged mixtures of pinyon pine (*Pinus edulis* Engelm.) and juniper (*Juniperus osteosperma* Torr.). Understory communities generally are sparse and include annual forbs: *Descurainia pinnata* and *Draba* spp.; some perennial grasses: *Bouteloua gracilis*, *Bouteloua curtipendula*, and *Aristida purpurea*; perennial forbs: *Eriogonum* spp. and *Chamaesyce fendleri*; shrubs: *Quercus turbinella*, *Purshia mexicana*, and cacti: *Opuntia erinacea*.

Site Assessment

Observations of the two sites suggested ecological degradation in two main forms: (1) low plant species diversity with communities dominated by dense pinyon and juniper overstories; and (2) reduced soil O horizons, particularly in intercanopy openings. Examination of repeat aerial photos showed that both sites had experienced some degree of overstory densification and tree encroachment

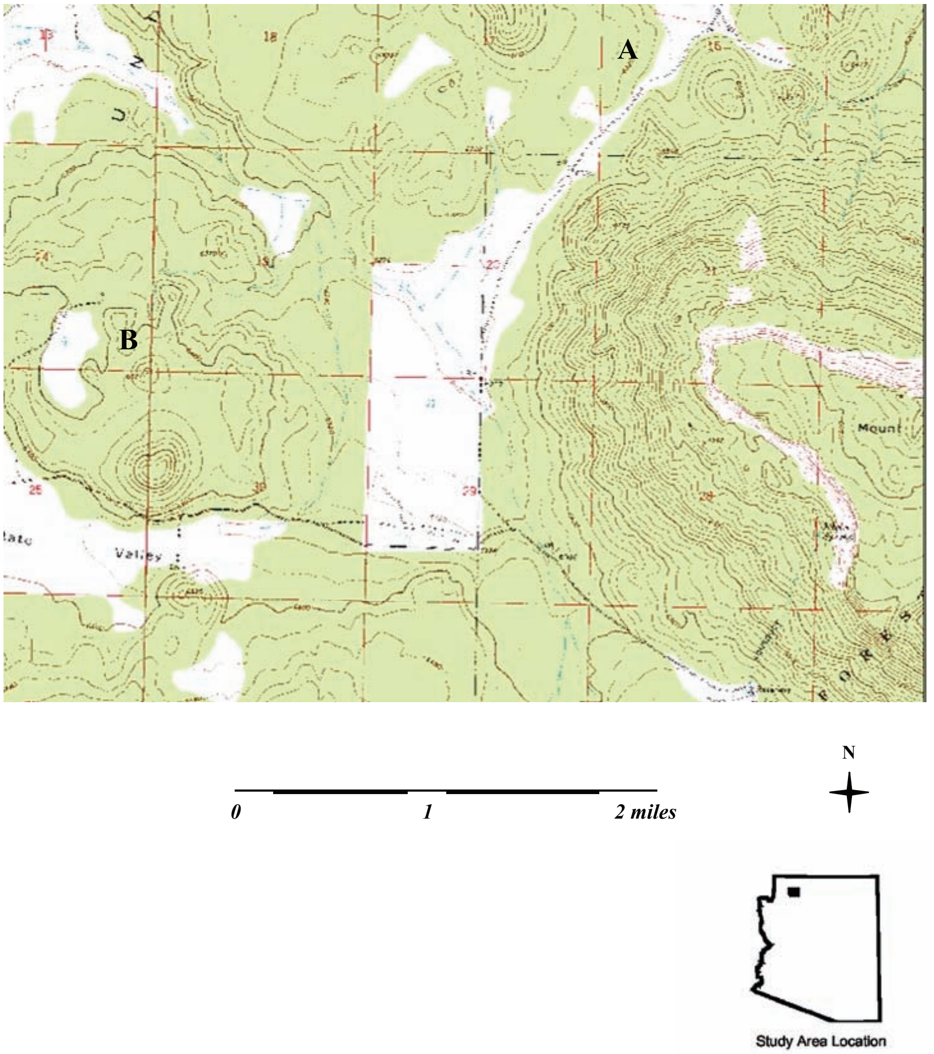

Figure 1—Map of Mount Trumbull area. **A** indicates the location of CR demonstration site and **B** shows the GP site.

from 1940 to 1992. We saw numerous dead shrub remnants on the sites, suggesting recent change in understory community characteristics. We suspected that these conditions may have been in part due to intensive livestock grazing. For example, a 1961 U.S. Forest Service report explained that grass cover, depleted by uncontrolled overgrazing before 1900, had not yet recovered (before 1975 the area was under Forest Service administration) (Unpublished report, BLM District Office, St George, UT). Overuse apparently continued through the 1960s; a range inspection report from 1969 stated that all three allotments in the area were in very poor condition and grass was almost 100% utilized each season (unpublished report, BLM District Office, St George, UT). Repeat aerial photographs indicated that a water catchment was developed at the GP site between 1940 and 1992 (fig. 1) and historical maps indicated that a pipeline was built to provide water to livestock near the CR site. Intensive grazing likely reduced native plant species diversity and impacted soil quality but its effect on natural disturbance patterns is less clear. Field observations at the two study sites revealed some charred wood; however, details regarding the fire history of the two sites are not known.

Measurements

At each site, we used aerial photographs and topographic maps to delineate a 9-ha (22.2-acre) area that was relatively homogenous in terms of overstory density, slope, and aspect. We divided these areas into two 4.5-ha (11.1-acre) units per site and randomly assigned units to receive restoration treatment or remain as a control. We established six 0.04-ha (0.1 acre) circular sampling plots on a 60-m (196.8 ft) grid in each unit. For long-term monitoring purposes, we used steel rebar to mark plot centers and georeferenced these points.

In 2002, we measured overstory, understory, and surface fuels characteristics on each plot. We measured diameter at root collar (DRC) for all live and dead trees and total height for all live and standing dead trees. We collected increment cores from all trees ≥20 cm DRC and from a 20% random subsample of smaller trees (< 20 cm DRC). Increment cores collected in the field were brought back to the laboratory, mounted on wooden slats, sanded, and crossdated (Stokes and Smiley 1968). We tallied dead tree structures (i.e., snags, logs, stumps) by condition class as described by Thomas and others (1979) and Maser and others (1979) for ponderosa pine. Tree seedlings (< 1.37 m (4.5 ft) in height) and shrubs were tallied on subplots (100 m^2; 0.025 acre) within the main plot. We used 10 quadrats (1m^2; 10.8 ft^2) per plot to sample cover of herbaceous species. We measured surface fuels and forest floor depth on planar transects (15.24 m; 50 feet) according to Brown (1974).

In 2002, a severe drought and bark beetle (*Ips confusus*) outbreak occurred. In 2003, before restoration treatments had been implemented, we resampled overstory structure on the plots to assess tree mortality. Signs of beetle presence (e.g., frass or pitch tubes) were noted. After thinning and spring seeding (see **Treatment**), we resampled overstory structure, regeneration, shrubs, fuels, and herbaceous understory (June 2004).

Pretreatment Conditions

We relied on assessment of present stand conditions and historical reconstruction to develop a restoration treatment prescription. Pretreatment measurements in 2002 indicated dense forest conditions at both sites (table 1). At the CR site,

Table 1—Overstory characteristics[1] at Craig Ranch (CR) and Goose Ponds (GP) demonstration sites in 2002 and 2004.

			TPH[2]			BA (m^2/ha)[5]			QMD (cm)[6]	
Site	Unit	Date	JUOS[3]	PIED[4]	Total	JUOS	PIED	Total	JUOS	PIED
CR	Control	2002	580	313	893	33.9	7.2	41.1	26.9	16.6
	Treated		387	251	638	25.9	5.1	31.0	29.4	16.2
	Control	2004	568	304	872	33.5	7.0	40.5	26.9	16.7
	Treated		206**	74**	280**	23.0	3.7	26.7	38.3*	26.8**
GP	Control	2002	144	498	642	14.5	8.3	22.8	35.1	14.7
	Treated		239	593	832	19.5	7.1	26.6	34.5	13.4
	Control	2004	144	267	411	14.5	3.1	17.6	35.1	11.5
	Treated		156	95	251	18.4	1.4	19.8	39.3	13.5

[1] Asterisks denote statistically different means for Control versus Treated conditions in 2004; * $P < 0.05$; ** $P < 0.01$.
[2] Trees per hectare (divide by 2.47 for trees per acre).
[3] Juniper (*Juniperus osteosperma*).
[4] Pinyon (*Pinus edulis*).
[5] Basal area (divide by 0.2296 for ft^2 per acre).
[6] Quadratic mean diameter measured at root collar (divide by 2.54 for inches).

juniper was dominant in the overstory in terms of number of trees (61% of TPH) and BA (83% of BA). At the GP site, juniper trees were outnumbered (29%) by pinyon but made up a greater proportion of the total basal area (73%). Cumulative age distributions derived from increment core analysis showed the majority of pinyon trees at both sites were less than 100 years old and a notable spike in their establishment occurred after 1950, particularly at the GP site (fig. 2). Juniper cores were often difficult to crossdate against known tree-ring chronologies. For such samples, we approximated tree age by conducting ring counts. Juniper at both sites had establishment peaks corresponding to the late 1800s to early 1900s (fig. 2). At the CR site, some junipers established as early as 1700-1725. At the GP site, we found no junipers that had established before 1800. Juniper seedlings (individuals less than 1.37 m (4.5 ft) in height) averaged 117-200 per ha (47-81 per acre) at the CR site and 50-117 per ha (20-47 per acre) at the GP site. Pinyon seedlings averaged 900-967 and 617-1433 per ha (364-391 and 250-580 per acre) at the CR and GP sites, respectively.

We estimated presettlement stand density for each site using age data from increment cores. Trees with center dates less than 1875 were considered presettlement in origin. To account for additional trees that died between 1875 and 2002, we included dead structures (i.e., snags, logs, and stumps) greater that 25 cm DRC in our presettlement density estimates. At the CR site, the number of trees estimated to exist in 1875 was 261 TPH (102.7 TPA) (table 2). Approximately 75% of these presettlement trees (live and dead) were juniper (196 TPH (79 TPA)). At GP, estimated presettlement density was 104 TPH (42 TPA) and approximately 60% of these trees were juniper (table 2).

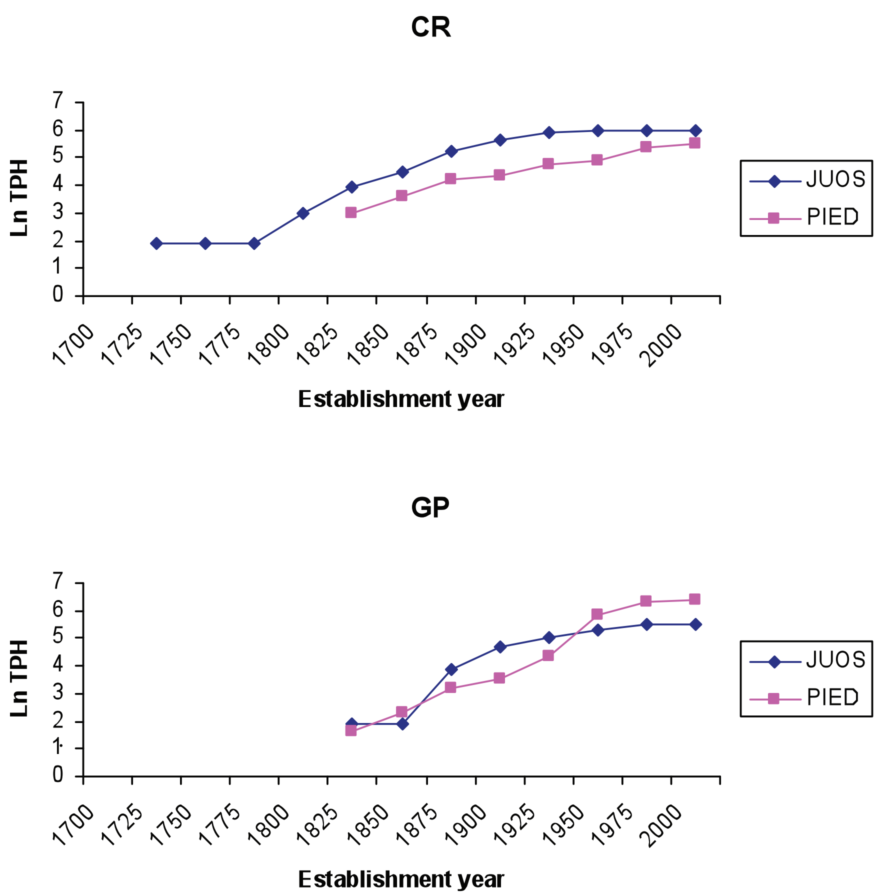

Figure 2—Cumulative establishment distributions for juniper (JUOS) and pinyon (PIED) at the CR and GP demonstration sites. Steeper areas of curves indicate periods of more rapid tree establishment.

Table 2—Number of trees per hectare (TPH) of juniper (JUOS) and pinyon (PIED) at three points in time: reconstructed to 1875, pretreatment in 2002, and posttreatment in 2004.

		Year					
		1875		2002		2004	
Site	Species	TPH	(%)	TPH	(%)	TPH	(%)
CR Treated	JUOS	196	75	387	61	206	73
	PIED	65	25	251	39	74	27
	Total	*261*		*638*		*280*	
GP Treated	JUOS	63	60	239	29	156	62
	PIED	41	40	593	71	95	38
	Total	*104*		*832*		*251*	

Understory vegetation was sparse at both sites (table 3). Mean cover was less than 7% at the CR site and less than 4% at the GP site. Species richness averaged 11.2-12.8 species per m^2 (10.8 ft^2) at CR and 4.2-4.7 at the GP site. Commonly occurring species at CR in 2002 included *Cordylanthus parviflorus, Draba* sp. (annual forbs), *Aristida purpurea*, *Bouteloua curtipendula*, *Bouteloua gracilis* (perennial grasses), *Arabis fendleri*, *Calochortus nuttallii* (perennial forbs), and *Opuntia erinacea* (cactus). Only one exotic species was found; *Lactuca serriola* occurred on ~3% of the quadrats in the treated unit. At GP, perennial forbs were most common, particularly *Chaenactis douglasii*, *Mirablis oxybaphoides*, and the exotic, *Marrubium vulgare*. Two other exotic species were found: *Bromus tectorum* on ~2% of the quadrats in both units and *Salsola tragus* on ~3% of quadrats in the control unit.

Woody surface fuels were minimal at both sites (table 4). Combined 1-hour and 10-hour fuels averaged 1.2 Mg/ha (0.53 T/acre) at the CR site and 1.7 Mg/ha (0.76 T/acre) at the GP site. Total forest floor depth at both sites averaged less than 1.3 cm (0.5 in). Total live canopy fuels averaged near 7.5 Mg/ha (3.3 T/acre) at both sites (table 4).

Table 3—Understory characteristics at Craig Ranch (CR) and Goose Ponds (GP) sites in 2002 and 2004 at Grand Canyon-Parashant National Monument.

Site	Unit	Date	Cover (%)	Richness[1]	Diversity[2]
CR	Control	2002	6.6	12.8	1.28
	Treated		5.1	11.2	1.11
	Control	2004	5.54	12.5	1.55
	Treated		3.68	13.7	1.6
GP	Control	2002	3.46	4.7	0.46
	Treated		1.15	4.2	0.46
	Control	2004	5.18	12	1.49
	Treated		2.85	10.7	1.29

[1] Richness is number of species per m^2 (divide by 0.0929 for number per ft^2).
[2] Shannon-Weiner's index of diversity.

Table 4—Fuels characteristics on control and treated units in 2002 and 2004 at the Craig Ranch (CR) and Goose Ponds (GP) demonstration sites at Grand Canyon-Parashant National Monument. Shown are litter and duff depths, surface fuel weights by moisture timelag class, and live canopy fuels.

			Depth (cm)		Surface Fuels (Mg/ha) [1]						Live Canopy (Mg/ha) [2]		
Site	Unit	Date	Litter	Duff	1H	10H	100H	1000HR	1000HS	Total	JUOS[3]	PIED[4]	Total
CR	Control	2002	0.4	0.4	0.6	1.5	2.9	0.0	0.0	5.0	7.93	2.97	10.9
	Treated		0.3	0.4	0.4	0.8	0.0	1.1	0.0	2.4	5.58	2.11	7.7
	Control	2004	0.2	0.4	0.7	1.2	3.8	0.0	0.0	5.7	7.82*	2.88	10.7*
	Treated		0.4	0.3	0.7	0.3	6.7	0.0	7.8	15.5	4.53	1.39	5.9
GP	Control	2002	0.1	0.8	0.7	1.6	1.4	1.8	2.3	7.8	2.88	3.71	6.6
	Treated		0.2	1.0	0.4	1.3	0.0	6.3	0.6	8.6	3.98	3.32	7.3
	Control	2004	0.2	0.7	0.8	1.9	2.4	3.0	1.8	9.9	2.88	1.51	4.4
	Treated		0.4	0.9	1.0	2.3	4.8	1.4	0.9	10.3	3.46	0.62	4.1

[1] Multiply Mg/ha by 2.4 for approximate tons per acre.
[2] Estimated using allometric equations provided by Grier and others (1992). Asterisks indicate statistically different means between treated and control units at P < 0.05. Biomass is foliage plus fine twigs.
[3] Juniper (*Juniperus osteosperma*).
[4] Pinyon (*Pinus edulis*).

Restoration Goals

Based on preliminary site assessments and analysis of pretreatment stand conditions, we developed the following restoration goals: (1) reduce overstory density to near presettlement levels; (2) reestablish historical overstory species composition; (3) reduce severe fire hazard; (4) reduce bark beetle susceptibility; and (5) reestablish a diverse understory. These goals represented an integration of reestablishing historical patterns of overstory structure and composition, a desire to increase biological diversity in understory communities, and a desire to protect important attributes such as old pinyon and juniper trees.

Treatment Prescription

Our restoration treatment approach entailed thinning trees to low densities, scattering slash, and seeding with native grasses. Specifically, we implemented the following prescription: (1) thin pinyon and juniper trees less than 25 cm (9.8 in) DRC, except for trees retained to replace presettlement evidence (i.e., dead tree structures >25 cm DRC) at a 2:1 ratio by species; (2) lop slash to 1 m (3.3 ft) or less in length and scatter material to cover bare soil; (3) seed with native plant species. Using tree increment cores, linear regression of establishment date and DRC data suggested that pinyon pine trees less than 25 cm DRC were likely to be less than 130 years of age and therefore postsettlement in origin (Establishment Date = 1977.12 - 4.25*(DRC); $R^2 = 0.57$; $P < 0.001$). Age-diameter relationships for juniper were poor ($R^2 < 0.15$). Retaining two postsettlement-aged trees to replace each dead presettlement structure was used as a conservative approach to restoring historical densities and also allowed for posttreatment mortality. Selection of replacement was based on species, size, form, and proximity to structure being replaced. Thinning was completed November 2003.

Selection of native plant species for seeding was based on observations of local occurrence, baseline data from belt transects, and community data reported in relict site literature (Mason and others 1967, Schmutz and others 1967, Thatcher and Hart 1974, Madany and West 1984, Rowlands and Brain 2001). We selected five grasses: *Bouteloua curtipendula*, *B. gracilis*, *Elymus elymoides*, *Oryzopsis hymenoides*, and *Sporobolis cryptandrus*; one forb: *Lupinus argenteus*; and four shrub species: *Amelanchier utahensis*, *Atriplex canescens*, *Ephedra viridis*, and *Rhus trilobata*. We used hand seeders to broadcast at a rate (18 kg/ha (16 lb/acre)) that approximated common standards for range rehabilitation (Clary 1988). However, we chose to seed half the amount in early spring and half in late summer in order accommodate germination and establishment requirements for both cool and warm season species. Using site preparation methods such as plowing or disking before seeding was not feasible. Similarly, we did not harrow or rake the restoration units after the seed was broadcast, but instead utilized thinning slash to provide cover and mulch for the seeds.

Data Analyses

We used logistic regression to test (alpha = 0.05) for relationships between probability of beetle-related pinyon mortality and tree height, DRC, age, and basal area growth at the GP site. We used Student's t-test to compare (alpha = 0.05) forest structure and understory characteristics at each of the two sites for pretreatment (2002) differences. When significant differences were found, we used analysis of covariance (ANCOVA) to test posttreatment differences with pretreatment conditions as a covariate. When no pretreatment differences were found, t-tests were used to compare posttreament means. Tree canopy biomass was estimated using allometric equations for pinyon (*Pinus edulis*) and juniper (*Juniperus monosperma*) provided by Grier and others (1992). We estimated surface fuel loading using equations provided by Brown (1974) and coefficients for ponderosa pine (*Pinus ponderosa*) fuels provided by Sackett (1980); no pinyon or juniper fuels coefficients were available in the published literature. Differences in biomass and fuels means between control and treated units were analyzed as described above for overstory characteristics.

Bark Beetle Effects

Bark beetle-related mortality of pinyon trees in 2003 was significantly related to tree size and growth. Probability increased with increasing height, DRC, and age. Mortality was less likely for trees that showed high relative BA growth. Mean height of beetle-killed trees was 4.2 m (13.8 ft) whereas surviving trees averaged 3.3 m (10.8 ft). Mean DRC was 12.3 cm (4.8 in) and 10.0 cm (3.9 in) for beetle-killed and surviving trees, respectively. Mean age of beetle-killed trees was 89 whereas surviving trees averaged 64 years. Beetle-killed trees showed a mean decrease of 15% in BA increment over the 10 years before mortality.

Treatment Effects

Implementation of the restoration thinning prescription significantly altered overstory structural characteristics at the CR site but did not affect those at the GP site, largely because of the greater impacts of beetle-related mortality (table 1). Thinning trees smaller than 25 cm DRC—while replacing dead structures greater than 25 cm DRC—reduced the number of juniper trees by nearly one-half and the number of pinyon by more than a factor of three at CR. Thinning at GP reduced the mean number of junipers by 83 TPH (33.6 TPA) but this did not result in a significant difference between control and treated conditions (table 1). Bark beetle-related mortality resulted in statistically similar pinyon densities between the control and treated units at GP (table 1). Basal area was not significantly affected by thinning treatment at either site (table 1). Diameter distributions, however, showed that dominance of small pinyon at CR was decreased by thinning. This was expressed as significantly greater QMD of both juniper and pinyon in the treated unit compared with the control at CR (table 1). At the GP site, diameter distributions were affected by both thinning and beetle-related mortality and no significant differences in QMD were found between the control and treated units (table 1).

Stand densities after thinning at both the CR and GP restoration units were similar to presettlement estimates (table 2). The total number of trees remaining after restoration thinning at CR was 280 TPH (113 TPA) and juniper comprised approximately 73%. There were 251 TPH (101.6 TPA) remaining after treatment at GP and juniper made up 62% of the residual number.

No significant differences in herbaceous plant cover, species richness, or diversity were detected between control and treated units at either site in June 2004 (table 3). Species composition was similar to pretreatment conditions. Two exotic species were observed at the CR site (treatment and control): *Lactuca serriola* (3% frequency) and *Tragopogon dubius* (2% frequency). Five exotic species were observed at the GP site. *Bromus tectorum* frequency in the GP treated unit was 1.7% in 2004 whereas it was not observed on these plots in 2002.

Thinning increased surface fuel loading at both sites, particularly for moisture-lag classes greater than 10-hours (table 4). Differences between control and treated units, however, were not statistically significant at either site. Changes in forest floor litter and duff depths due to treatment were minimal and remained low after treatment (table 4). Canopy biomass was significantly reduced by thinning at the CR site (table 4). Due to beetle-related mortality that occurred in the both treated as well as the control units, no significant differences were found in live canopy biomass at GP site in 2004 (table 4).

Discussion

Various lines of evidence, including historical and contemporary aerial photographs, diameter and age distributions, and dendrochronological reconstructions indicated a transition at both study sites from previously more open stand conditions existing in the late 1800s to closed conditions found at the site in 2002. At the CR site, the number of trees in 2002 was more than twice the number estimated to be present in 1875. This difference was even more dramatic at the GP site where 2002 density was greater than the estimated presettlement number of trees by a factor of eight. In addition to changes in overstory density, both sites appeared to be moving toward increased importance of pinyon relative to juniper. Large junipers were present at both sites and this was reflected in greater BA in comparison to pinyon. Age data suggested that peak juniper establishment was around 1875-1900 at CR and 1875-1925 at GP whereas pinyon establishment appeared to peak around 1950 at both sites. It should be noted that precise crossdating of juniper is difficult and these establishment dates are best considered as approximations. Pinyon seedlings outnumbered juniper by a factor of four or more at both sites.

Comparable postsettlement changes have been described on pinyon-juniper sites throughout the Southwest and Great Basin (Blackburn and Tueller 1970, West and others 1975, Tausch and others 1981, Jacobs and Gatewood 1999, West 1999, Romme and others 2003, Landis and Bailey 2005). For example, on four black sagebrush (*Artemisia nova*) sites in Nevada, Blackburn and Tueller (1970) concluded that juniper (*J. osteosperma*) initially invaded open sage communities whereas pinyon became more prevalent as overstory densities increased. Age distributions indicated that juniper trees were present as early as 1725 but establishment began to dramatically increase around 1850 for juniper and 1920 for pinyon. Similarly, Tausch and others (1981) reported that increases in tree dominance since the early 1800s on eastern Nevada and western Utah sites were driven by pinyon establishment. Factors responsible for driving these structural changes include relaxation of interspecific competition due to intensive grazing, increases in woody vegetation ("nurses" for pinyon establishment—see below), fire exclusion due to livestock grazing (removal of fine fuels) and active suppression, warmer, moister climatic patterns of the late 1800s to early 1900s, and recent increases in atmospheric CO_2 (Leopold 1924, Burkhardt and Tisdale 1976, Young and Evans 1981, West 1999, Miller and Tausch 2001, Romme and others 2003).

At the GP site, a bark beetle outbreak reduced overstory density of pinyon and this could be interpreted as a natural disturbance that counteracts recent increases in density and provides restoration benefits. Although this is true in part, at the GP site beetles preferentially attacked larger, older pinyon—elements of the historical stand conditions that are desirable to retain for conservation (e.g., wildlife habitat) and multi-resource reasons. Further, high density of standing dead pinyon may represent increased fire hazard for one or two years while dead needles remain on the tree.

Similar patterns of beetle activity were found by Negrón and Wilson (2003) who reported that tree diameter (DRC) and mistletoe infestation were good predictors (72% correct classification) of beetle attack on pinyon near Flagstaff, Arizona. Stand density was also positively related to beetle attack. In order to reduce the probability of beetle-related mortality in pinyon-juniper woodlands, reducing pinyon stand density index (SDI; Reineke 1933) to values of 50 or less are recommended (Negrón and Wilson 2003). Thinning at the CR site reduced pinyon SDI to 81 from 122 in 2002. Thinning and mortality reduced SDI at the GP site to 34 from 212 in 2002. In the control unit, SDI was 75 in 2005.

The restoration prescription implemented at the two sites appeared to be effective in reduce stand density to levels similar to those suggested by dendrochronological reconstructions. The majority of trees removed from both sites were small pinyon (table 2); this increased the relative importance of juniper and restored overstory composition to characteristics similar to those existing in the late 1800s. Selective tree removal using chainsaws is preferable to indiscriminate techniques such as anchor chaining or cabling that may cause substantial soil disturbance and stimulate regeneration of juniper (Jacobs and Gatewood 1999, Brockway and others 2002). The approach we tested conserves all large trees. Clearer description of historical patterns could be provided by reconstruction models that utilize dendrochronological information, tree death date predictions (i.e., decay rates, harvesting records, insect outbreak dates, etc.), and back-growth equations. Fire history information also would be helpful in developing restoration prescriptions for closely emulating historical conditions. Presettlement fire characteristics in pinyon-juniper woodlands are poorly understood (Romme and others 2003, Baker and Shinneman 2004) and we are currently pursuing fire history research on other northern Arizona and New Mexico sites.

In our study, no significant differences in herbaceous parameters were found between the treatment (slash additions and seeding) and control units. Posttreatment measurements, however, were conducted just four months after seeding was completed. Further monitoring is necessary before conclusions can be made regarding the effectiveness of treatment on increasing understory abundance and species richness.

Thinning significantly reduced live canopy biomass as compared with the control unit at the CR site. This represents a decrease in crown fire hazard, although we did not attempt to model potential fire behavior. At the GP site, bark beetle-related mortality decreased live canopy biomass although trees killed by beetles in the control unit will retain their needles for one or two years and create an increased hazard. Thinning slash lopped and scattered at both sites did not significant affect woody surface fuel loads. This may reflect the combined influences of thinning only small trees and large interspace areas that were targeted for slash dispersal.

Other pinyon-juniper restoration experiments have tested slash dispersal and seeding treatments to promote understory recovery (Jacobs and Gatewood 1999, Brockway and others 2002). Results have been variable. For example, Jacobs and Gatewood (1999) found that lopping and scattering slash into interspaces substantially increased herbaceous cover at two sites in northern New Mexico, although seeding did not significantly contribute to the increases. In contrast, Brockway and others (2002) reported positive effects of tree removal on grass cover but no significant differences between slash removal and slash dispersal treatments at a site in central New Mexico. Stoddard (unpublished) reports finding significant increases in plant cover on plots with slash and seed additions compared with control plots in interspaces adjacent our demonstration units at Mount Trumbull. Thinning slash that is scattered into degraded interspaces may increase rates of seedling establishment by altering microsite conditions. Some of these changes may include dampening of soil temperature fluctuations and extremes, increasing soil moisture content, providing structure that traps seeds, and reducing erosion (Jacobs and Gatewood 1999, Hastings and others 2003, Stoddard and others 2005).

Conclusions

Although there is still much that is not known regarding historical conditions at the two demonstration sites, the restoration treatment implemented appeared to be effective at reestablishing overstory characteristics more similar to those of the late 1800s. Further monitoring of understory changes is needed. The treatment also reduced fuel hazard and conserved large, old pinyon and juniper trees. The permanent plots established will allow further assessment of ecosystem recovery and assist in the adaptive management process.

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