Ecological Restoration Experiments (1992-2007) at the G.A. Pearson Natural Area, Fort Valley Experimental Forest

Margaret M. Moore, *School of Forestry, Northern Arizona University (NAU), Flagstaff, AZ*; **W. Wallace Covington,** *NAU*; **Peter Z. Fulé,** *NAU*; **Stephen C. Hart,** *NAU*; **Thomas E. Kolb,** *NAU*; **Joy N. Mast,** *Carthage College, Kenosha, WI*; **Stephen S. Sackett, (ret.)** *USFS Pacific Southwest Research Station, Riverside, CA*; *and* **Michael R. Wagner,** *NAU*

Abstract—*In 1992 an experiment was initiated at the G. A. Pearson Natural Area on the Fort Valley Experimental Forest to evaluate long-term ecosystem responses to two restoration treatments: thinning only and thinning with prescribed burning. Fifteen years of key findings about tree physiology, herbaceous, and ecosystem responses are presented.*

Introduction and Background

Prior to fire exclusion in the late 19th century, ponderosa pine forests in northern Arizona and the Southwest were described as a matrix of grass-dominated openings interspersed with smaller groups or stands of pine (Cooper 1960, Pearson 1950). Today, most southwestern ponderosa pine forests have a closed overstory canopy intermixed with a few fragmented, remnant grass openings (Covington and Moore 1994, Covington and others 1997). This study was initiated in 1992 at the G.A. Pearson Natural Area (GPNA) on the Fort Valley Experimental Forest (FVEF) to restore a reasonable approximation of the presettlement ponderosa pine structure and function and to evaluate long-term ecosystem responses to two restoration treatments (Covington and others 1997). This "presettlement or pre-fire-exclusion model" quickly returned tree structure to what it was in pre-Euro American settlement times through thinning postsettlement trees, and re-introduced low-intensity surface fire (Covington and others 1997). Ideally, these treatments would reduce the threat of unnaturally intense crown fires and bark beetle attack, and allow this ponderosa pine ecosystem to respond adaptively to climate change. Tree physiology,

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herbaceous vegetation, and ecosystem responses within thinning and prescribed burning treatments were examined. Here we report key findings; readers should refer to specific publications listed in Appendix I for details.

Methods

Study Site

This study was conducted on a decommissioned portion of the GPNA, located 10 km northwest of Flagstaff, Arizona in the FVEF, Coconino National Forest. The 4.3 ha study site ranges from 2195-2255 m in elevation, and has a flat to gently rolling topography. Soils are Brolliar stony clay loams, and a complex of fine, smectitic Typic Argiborolls and Mollic Eutroboralfs (Kerns and others 2003). The average annual temperature is 7.5°C. Average annual precipitation is approximately 57 cm, with approximately half occurring as rain in July and August and half as snow in the winter. Drought was common during this study, with 2002 being especially severe (Figure 1). In 1992, a 2.4 m tall fence was constructed to exclude wild and domestic ungulates from the GPNA restoration experiment. The specific portion of GPNA used in this study was never harvested for timber (Avery and others 1976). The last major fire in the area occurred in 1876 (Dieterich 1980). Ponderosa pine (*Pinus ponderosa* Laws. var. *scopulorum* Engelm.) is the only overstory species on the study site and Fendlers ceanothus (*Ceanothus fendleri* Gray) is the only shrub. The understory is dominated by perennial graminoid and forb species.

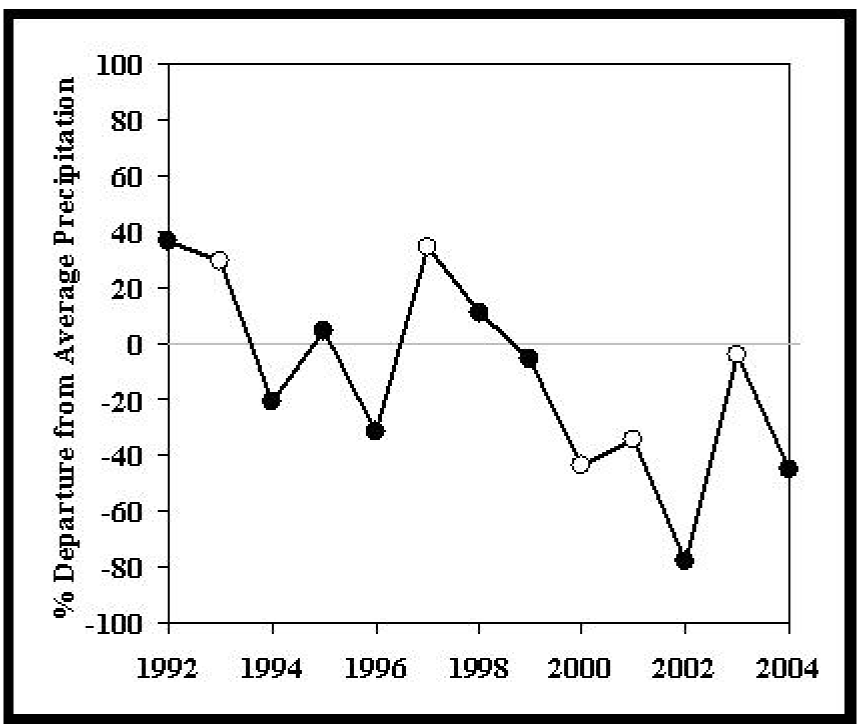

Figure 1. Annual precipitation from 1992-2004 as percent departure from the long-term (51 yr) average. Annual totals included the 12 months of precipitation before vegetation sampling (previous September through August). Dark symbols indicate years in which vegetation was sampled (1992-2004). From Moore and others (2006).

Treatments and Patch Types

In 1992, five 0.2-0.3-ha plots were established in each of three treatments: 1) thinning from below (thinning; see Figure 2); 2) thinning from below plus forest floor manipulation with periodic prescribed burning (composite); and 3) control. The five control treatment plots were located non-randomly on one side of the study site, while the thinning and composite treatment plots were assigned randomly. This design was necessary so that the fuel break created by the treated plots would protect the historical buildings of the adjacent FVEF.

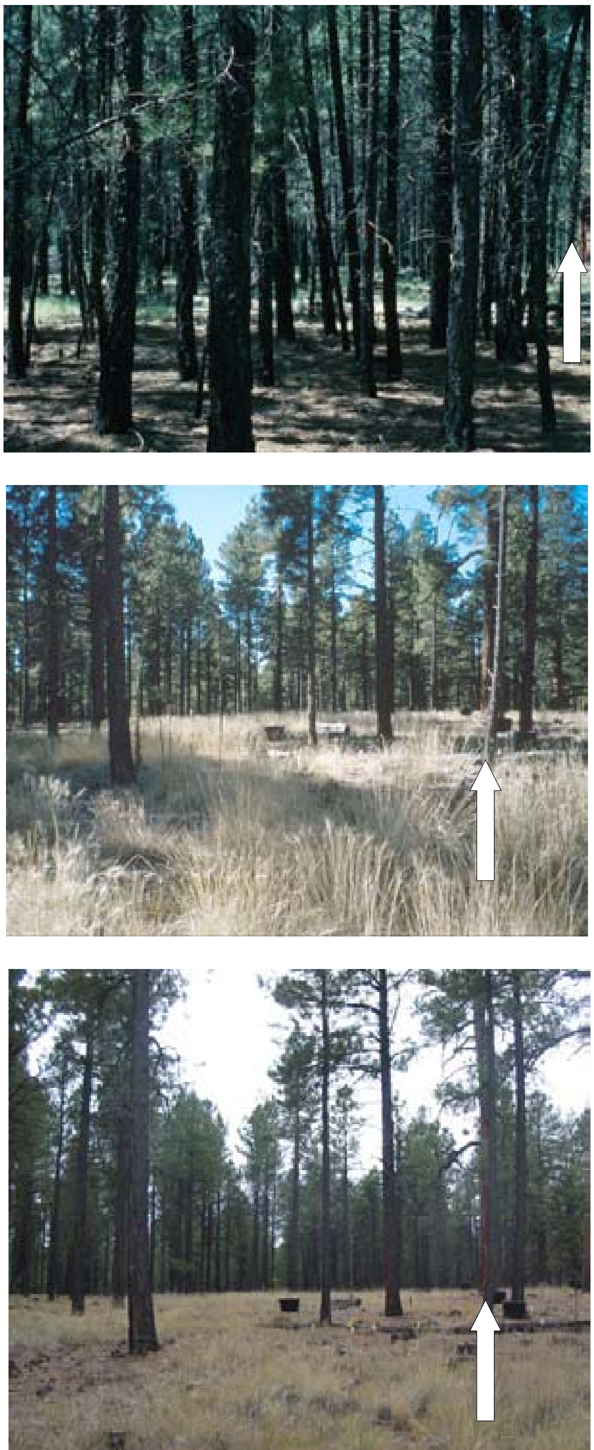

Figure 2. Repeat photographs of a thinning treatment photo point (photo point 302) in the GPNA in 1992, prior to treatment (top photo), in 1998, 5 years after thinning (middle photo), and in 2004, 11 years after thinning (bottom photo). The arrows highlight the same tree (approx. 15 cm at dbh) in each photo. All photos were taken in early autumn (September to early October). Note the difference in herbaceous standing crop between 1998, an average year in precipitation, and 2004, which was > 40% below normal. Photo credits: Ecological Restoration Institute, Northern Arizona University. From Moore and others (2006).

Each treatment plot contained four patch types: presettlement tree groups, unthinned postsettlement trees ("postsettlement retained"), thinned postsettlement trees ("postsettlement removed"), and remnant grass openings (Figure 3). Presettlement tree patches consisted of groups of two or more large trees (mostly > 30 cm) that established prior to 1876. Postsettlement retained patches consisted of a group of small-diameter (< 30 cm) trees that established after 1876. Postsettlement removed patches consisted of an area where most or all postsettlement trees were thinned and removed from the site, thereby creating an opening. Remnant grass patches were located within open areas between patches of trees.

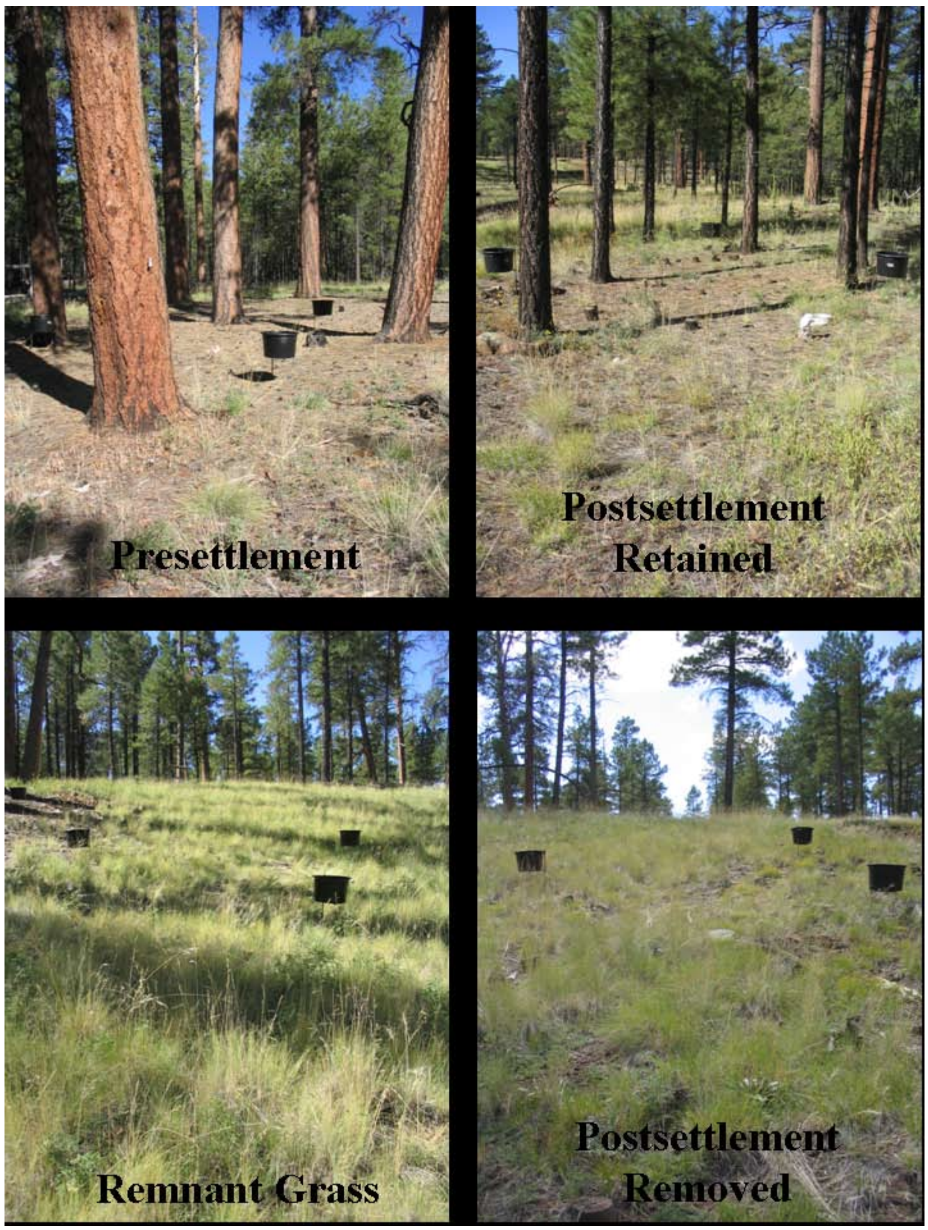

Figure 3. Example photos of each patch type used in this study: (a) presettlement, (b) postsettlement retained, (c) remnant grass, and (d) postsettlement removed. Plot centers for smaller subplots are located between black buckets. Photo credits: Ecological Restoration Institute, Northern Arizona University. From Laughlin and others (2006).

Pretreatment data were collected in 1992. In 1993, thinning resulted in the removal of 2226 trees ha^{-1}. All presettlement trees and trees > 40.6 cm diameter at breast height were retained. In addition, 5-15 smaller diameter trees were retained in each plot to replace stumps, snags, and downed logs and recreate the group pattern of the presettlement forest (Covington and others 1997, Edminster and Olsen 1996, White 1985). Pine basal area was reduced by 45% in the postsettlement retained patches and by 95% in the postsettlement removed patches. The first prescribed burn occurred in October 1994 and subsequent burns occurred in October 1998, 2002, and 2006. See Covington and others (1997) and subsequent publications listed in Appendix I for more detailed accounts of experimental design, data collections and analyses.

Results and Discussion

Stand Structure

Age data were used to document 1876 forest structure (the year of the last major fire), to monitor treatment effects on old-tree persistence, and to test methods of reconstructing past forest conditions (Mast and others 1999). The oldest living tree in 1992 had a center date of 1554 but the oldest tree that was alive in 1876 had a center date of 1333 (Figures 4, 5).

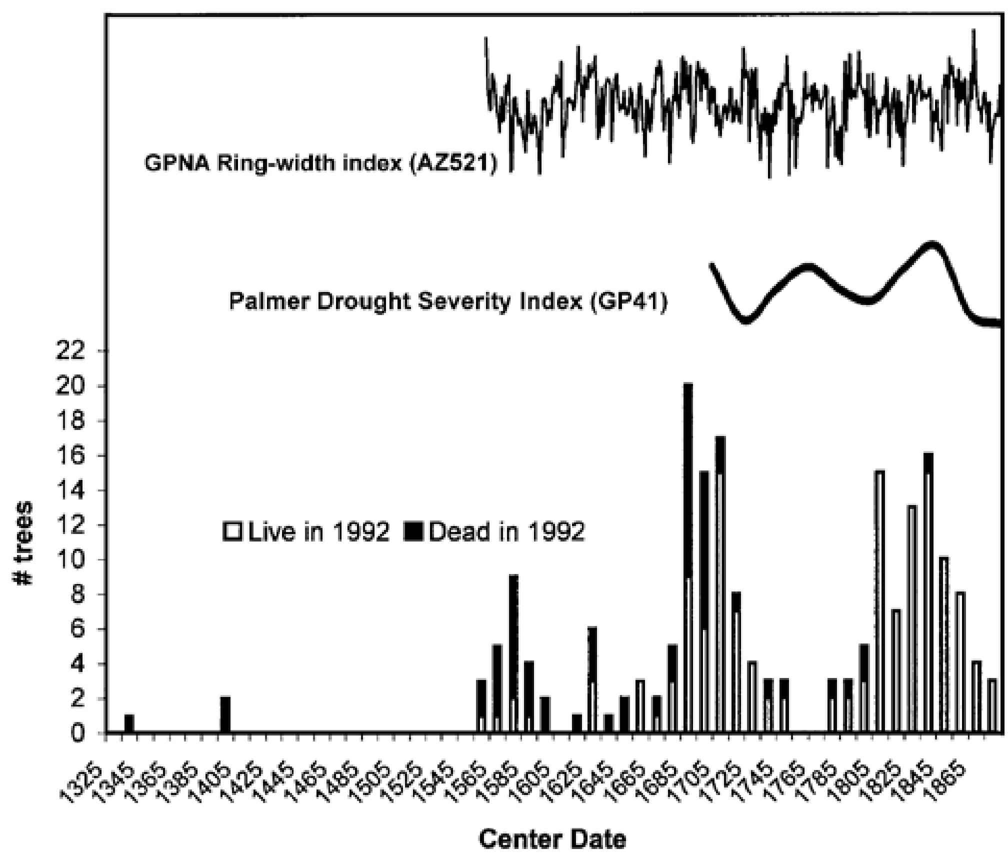

Figure 4. Reconstructed 1876 age structure of the sampled 4.7-ha ponderosa pine stand at the G.A. Pearson Natural Area (GPNA), Arizona. Dates are midpoints of 10-year age classes. Center dates of 203 trees are shown. The smoothed reconstructed Palmer Drought Stress Index GP-41 (Cook and others 1996) and a standardized tree-ring width index for the GPNA (AZ521. CRN [Graybill 1987]) are shown for comparison with the presettlement tree establishment dates. All the indices are dimensionless. From Mast and others (1999).

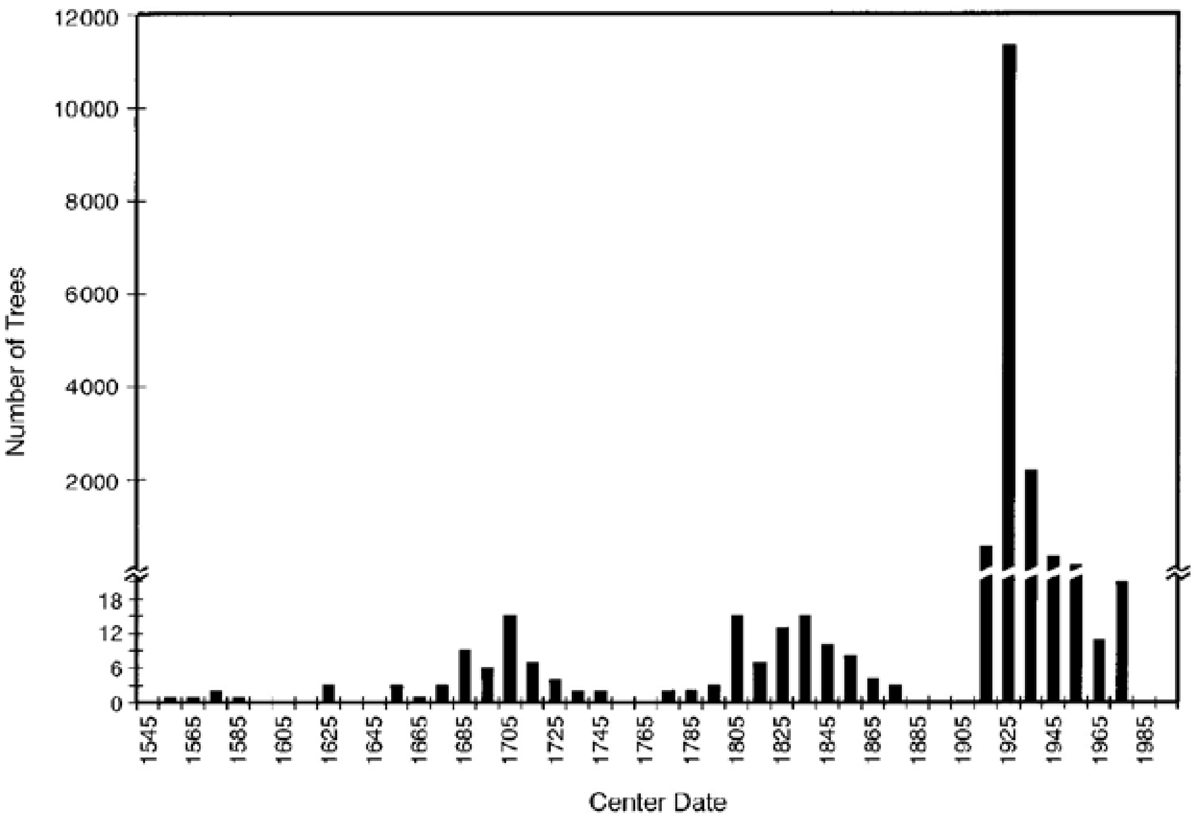

Figure 5. Age structure in 1992 after 116 yr of fire exclusion. The graph is a composite of dated trees of presettlement origin and a subsample of dated trees of postsettlement origin. From Mast and others (1999).

Approximately 20% of the trees were ≥ 200 yr old in 1876 with ages ranging to 540 yr. If dead trees had not been included in the reconstruction, the distribution would have been biased toward younger trees and a 40% shorter age range. The presettlement age distribution was multimodal with broad peaks of establishment. Although fire disturbance regimes and climatic conditions varied over the centuries before 1876, a clear relationship between these variations and tree establishment was not observed. Due to fire exclusion, reduced grass competition, and favorable climatic events, high levels of regeneration in the 20th century raised forest density from 60 trees ha^{-1} in 1876 to 3000 trees ha^{-1} in 1992. This ecological restoration experiment conserved all living presettlement trees and reduced the density of young trees to near-presettlement levels.

Effect of Treatments on Old-Growth Trees

The old, presettlement trees responded to thinning in the first year with greater water uptake, stomatal conductance, net photosynthetic rate, and leaf nitrogen concentration, and these physiological changes persisted through at least the seventh post-treatment year (Feeney and others 1998, Stone and others 1999, Wallin and others 2004). Thinning consistently increased bole basal area increment starting in the second post-treatment year and for the next 10 years, except in the severe drought of 2002 (Figure 6, Kolb and others 2007). Thinning also reduced crown dieback over the first 10 post-treatment years (Kolb and others 2007). Resin flow

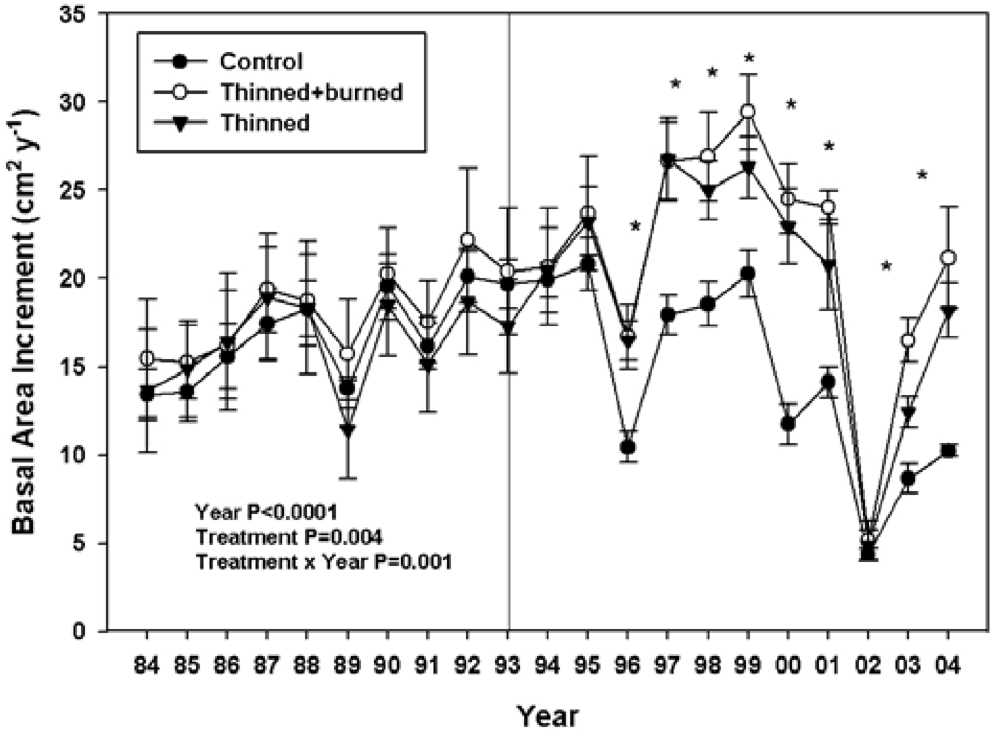

Figure 6. Basal area increment of old ponderosa pine at the GPNA in northern Arizona was stimulated by thinning treatments and increment was similar for trees in thinned alone and thinned plus prescribed burned treatments. The vertical line shows the year of treatment. The P values are from repeated measures MANOVA for the post-treatment years. * indicates significant ($P<0.05$) differences among treatments in ANOVA by year. Another MANOVA showed no difference in increment among trees in different treatments for the 10 pretreatment years (1984-1993). Error bars are one standard error of the mean. From Kolb and others (2007).

defense against bark beetles was consistently stimulated by the composite treatment only (Feeney and others 1998, Wallin and others 2004). Two cycles of burning in the composite treatment reduced leaf nitrogen concentration compared with the thin alone treatment (Wallin and others 2004), but growth was similar for trees in both treatments in most post-treatment years (Kolb and others 2007).

Effects of Treatments and Patch Type on Herbaceous Plants

Total herbaceous standing crop, measured between 1994 and 2004, was significantly higher on the treated areas than on the control over the entire post-treatment period, but did not differ between the two treatments (Moore and others 2006). In general, the graminoid standing crop responded within several years after the initial treatments and continued to increase through time, until a series of severe droughts reduced standing crop to pretreatment levels (Figure 7). C_3 graminoids (primarily bottlebrush squirreltail, *Elymus elymoides*) dominated the standing-crop response. C_4 graminoids, such as mountain muhly (*Muhlenbergia montana*) had a minimal response to restoration treatments, possibly because this species was less abundant before the experiment began or adversely affected by autumn burning. Legumes and forbs exhibited a 4–5 year lag response to treatment. Patch type had a greater influence on the herbaceous standing crop than treatment effect (Figure 8, Laughlin and others 2006), and differed by functional group and species. Species richness and composition differed among patch types prior to treatment, and there was a long lag time (11 and 5 yrs, respectively) before any treatment differences were significant (Laughlin and others 2008).

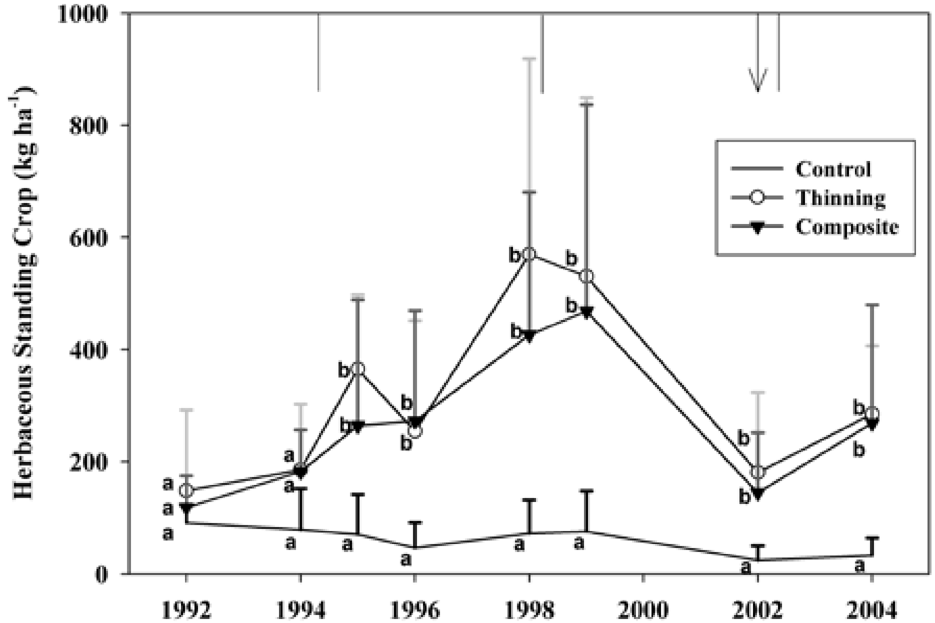

Figure 7. Total herbaceous standing crop (mean + SD) in three treatments between 1992 and 2004. Data from 1992 represent pretreatment data. Lowercase letters indicate significant differences among treatments within years. The arrow denotes the extreme drought year (2002) and vertical lines denote prescribed burn years. From Moore and others (2006).

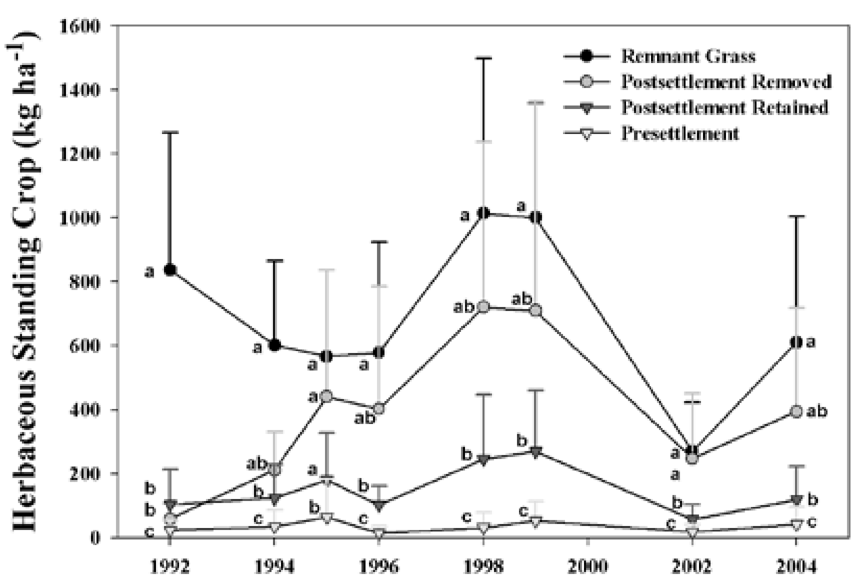

Figure 8. Total herbaceous standing crop (mean +1 SD) among patch types from 1992 to 2004. Pairwise comparisons of patches within years are reported for each year. From Laughlin and others (2006).

Effects of Treatments on Ecosystem Processes

During the first two years following treatments, total net primary productivity was similar among control and restored (treated) plots because a 30-50% decrease in pine foliage and fine-root production in restored plots was balanced by greater wood, coarse root, and herbaceous production (Figure 9, Kaye and others 2005). Elemental flux rates (C, N, and P) in control plots generally declined more in a drought year than rates in restored plots (Kaye and others 2005). Net N mineralization and nitrification rates generally were higher in restored compared to control plots (Kaye and others 2005), and were also typically higher in grass patches than under pine trees (Kaye and Hart 1998a). Estimates of N and P loss via leaching were low and similar among treatments (Kaye and others 1999). During this initial response period, soil CO_2 efflux (a measure of below-ground biological activity) was similar among treatments during a near-average precipitation year, but was higher in restored plots during a dry year (Kaye and Hart 1998b). A similar interaction between water availability and treatment responses on soil CO_2 efflux was found seven years after the initial treatments were implemented (Boyle and others 2005). Seven years post-treatment, soil enzyme activities were higher in the composite restoration plots than the other treatments (moist periods only), and the community-level physiological capacities of soil microorganisms in composite restoration plots (dry period only) also differed from the other treatments (Boyle and others 2005). Surface soil temperature in the composite restoration plots during the growing season has consistently been 1-5 °C higher than in the control plots, with the thinning restoration plots intermediate. In contrast, surface soil water content generally showed the opposite pattern, with soil water content higher in control plots (Boyle and others 2005).

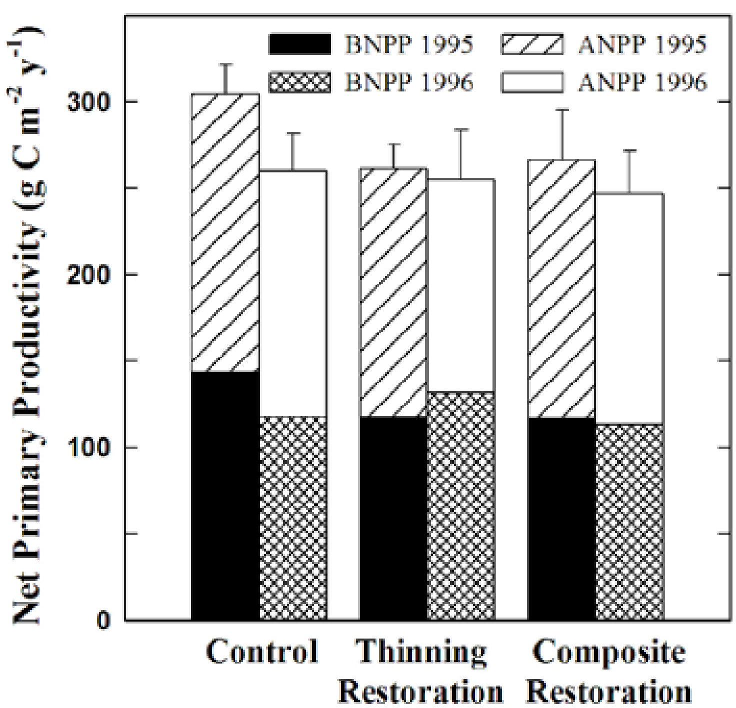

Figure 9. Total net primary production (NPP) in untreated control, thinning restoration, and composite restoration treatments. Bars depict means +1 SE (n = 5 plots). There were no significant differences among treatments in aboveground NPP (ANPP), belowground NPP (BNPP), or total NPP for individual years or repeated-measures ANOVA ($P > 0.10$). From Kaye and others (2005).

Simulation modeling with the ecological process model FIRESUM showed that repeated surface fire was predicted to maintain the open forest structure of the composite treatment. In contrast, the thin-only treatment was forecast to return to high forest densities similar to those of the control within a century. These simulation results suggest restoration of disturbance process, as well as characteristic forest structure, are both important for sustaining the function of these forests (Covington and others 2001).

Summary

The "presettlement model" restoration approach quickly returned tree structure to what it was in pre-Euro American settlement times through thinning postsettlement trees. Low-intensity surface fires were also re-introduced every four years. Surprisingly, few differences were found between the thinned and composite (thinned and burned) treatments, although the treated plots did differ from the untreated control. Old-growth tree growth, herbaceous standing crop, net N mineralization and nitrification rates were higher in restored compared to control plots. Subtle but important variables such as resin flow defense against bark beetles and soil enzyme activities were higher in the composite treatment. Patch type had a greater influence than the treatment on specific variables such as herbaceous standing crop. A major role of fire in maintaining ecosystem function is as a manager of vegetation structure rather than as a direct mineralizer of nutrients "tied-up" in detritus (Hart and others 2005). Thinning and composite treatments both do a good job "returning" ecosystem function but repeated fire maintains the structure while thinning alone will eventually allow the ecosystem to return to its pretreatment state. Inter-annual variability in climate plays a key role in how the ecosystem responds to any treatment.

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Appendix I

This appendix contains all research publications and graduate student theses and dissertations from the G. A. Pearson Natural Area (GPNA) restoration experimental site from fall 1992 through spring 2008.

Articles and Proceedings:

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