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Working Papers in Southwestern Ponderosa Pine Forest Restoration

Restoring Spatial Pattern to Southwestern Ponderosa Pine Forests

June 2008

NORTHERN ARIZONA UNIVERSITY

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Ecological restoration is a practice that seeks to heal degraded ecosystems by reestablishing native species, structural characteristics, and ecological processes. The Society for Ecological Restoration International defines ecological restoration as "an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability….Restoration attempts to return an ecosystem to its historic trajectory" (Society for Ecological Restoration International Science & Policy Working Group 2004).

In the southwestern United States, most ponderosa pine forests have been degraded during the last 150 years. Many ponderosa pine areas are now dominated by dense thickets of small trees, and lack their once diverse understory of grasses, sedges, and forbs. Forests in this condition are highly susceptible to damaging, stand-replacing fires and increased insect and disease epidemics. Restoration of these forests centers on reintroducing frequent, low-intensity surface fires—often after thinning dense stands—and reestablishing productive understory plant communities.

The Ecological Restoration Institute at Northern Arizona University is a pioneer in researching, implementing, and monitoring ecological restoration of southwestern ponderosa pine forests. By allowing natural processes, such as fire, to resume self-sustaining patterns, we hope to reestablish healthy forests that provide ecosystem services, wildlife habitat, and recreational opportunities.

The ERI Working Papers series presents findings and management recommendations from research and observations by the ERI and its partner organizations. While the ERI staff recognizes that every restoration project needs to be site specific, we feel that the information provided in the Working Papers may help restoration practitioners elsewhere.

This publication would not have been possible without funding from the USDA Forest Service. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the United States Government. Mention of trade names or commercial products does not constitute their endorsement by the United States Government.

Cover photo: A clump of ponderosa pine on limestone soils to the southeast of Flagstaff, Arizona. Note the interlocking crowns of the taller trees and the stunted growth of the overtopped trees within the clump. *Photo by Dave Egan*

Introduction

Until recently, forest managers have largely ignored the value of maintaining dynamic spatial patterns in forested ecosystems. In the American Southwest, where the norm is overstocked forests that are extremely susceptible to catastrophic fires and/or insect infestations and disease, restoring a spatial pattern of openings and tree groups would help alleviate these threats and move the forests within their historic range of variability. This ERI working paper focuses on restoring a dynamic spatial pattern to ponderosa pine forests in the American Southwest. It also addresses basic questions that land managers and others have about how to restore active spatial patterns across the forested Southwest.

Some of the fundamental ideas suggested in this working paper are:

- Forest openings are critical to the ecological functioning of ponderosa pine ecosystems. Along with decreasing the number of trees, the restoration of openings should be a central focus of ecological restoration efforts throughout the forested Southwest.
- Because each site is unique, the importance of site analysis cannot be emphasized enough. Soils, topography, aspect, and the historic spatial structure of pre-European settlement openings and trees should be analyzed in order to help guide the process of pattern development and restoration.
- Following restoration treatments, periodic, surface fires—either human-set or from lightning—are the best way to maintain forest openings and restore natural processes. If not burned (or thinned) after treatment, the openings will fill in with trees and the health of the stand will again become compromised.

Dynamic Spatial Patterns in Plant Communities

Early plant ecologists, such as Cowles (1899) and Watt (1947), described plant communities as patchy and shifting, both spatially and temporally. Building on their ideas and findings, other ecologists have studied the causes and development of spatial patterns within plant communities. Analyzing the work of these more recent ecologists, Dale (1999) identified three general reasons for spatial patchiness: 1) the reproductive tendencies of certain plants (especially clonal plants, such as aspens and braken fern), 2) environmental factors (e.g., soil type, soil depth, soil nutrients, topography/aspect, bedrock type and patterns, climatic patterns—both regional and local), and 3) disturbance processes (e.g., fire, windthrow, flooding, insects and diseases, disturbances by animals/humans).

While the reproductive and structural tendencies of plants are important, they tend to produce relatively small-scale patterns (hundreds of acres) and are dependent on environmental factors and/or disturbance processes for their location, spatial extent, and longevity. Thus, while knowledge of these reproductive tendencies is important, developing an understanding of the environmental conditions and disturbance processes that exist within a plant community or an ecosystem provides an even more essential understanding of vegetative patterns on the landscape and the reasons for their existence.

Environmental factors provide the backdrop upon which plants grow and sort themselves into communities. These factors are, for most part, stable and long-lived and, if left alone (i.e., undisturbed), would result in a "balanced nature" or climax condition where species adapted to specific environmental conditions would form integrated, self-perpetuating communities and ecosystems (White 2006). However, the natural world does not operate that way. Instead, it consists of a relatively stable foundation of environmental elements with a shifting vegetative cover (where it is vegetated) that responds to, and is adapted to, disturbances and disturbance events. This results in plant communities and ecosystems that are dynamic and in flux (White 2006).

Many ecologists (e.g., Bormann and Liken 1979, Pickett and White 1985, Clark 1991) have studied the importance of disturbance events in creating pattern in ecosystems. In doing so, they have developed various terms for this phenomena. For example, Heinselman (1973), after examining the effects of fire on a boreal forest landscape of northern Minnesota, described what he found as a "shifting mosaic." Remmert (1991) used the term, "mosaic-cycle" to explain the interaction between disturbance events, regeneration, and spatial pattern. More recently, various plant ecologists and landscape ecologists have begun to study and describe the "resistance" and "resilience" of a spatial pattern to disturbance (Jentsch et al. 2002).

Spatial Pattern in Frequent-fire Southwest Forest Landscapes

The spatial pattern of most ponderosa pine forests in the American Southwest prior to Euro-American settlement was typically more open and patchy than today, with large trees often growing in uneven-aged groups in a matrix of grassy, savanna-like gaps (Whipple 1856; Beal 1858; Pearson 1923; Cooper 1960, 1961; White 1985; Covington and Moore 1994; Mast et al. 1999). This pattern was initially created by environmental factors (e.g., soil types, topographic conditions, climate), and perpetuated and modified by fire caused by lightning or Native Americans or some combination of both (Swetnam and Baisan 1996, Covington 2003). Native Americans likely burned these landscapes to increase habitat for game species, enhance seed production, create proper material for basketmaking, and encourage the growth of edible or medicinal plants (Pyne 1982, Stewart 2002, Alcoze 2003); or for warfare purposes (Seklecki et al. 1996). Lightning during annual dry periods would, likewise, have ignited fires that killed tree seedlings and saplings and promoted the growth of a grassy, herbaceous understory (Swetnam and Baisan 1996, Allen 2002).

While other disturbances (e.g., tree disease, insect outbreaks) existed prior to European settlement, these natural forces caused only relatively small-scale changes in the spatial pattern (Larsson et al. 1983). Fire, regardless of its cause, was the disturbance factor that modified the spatial pattern of forested landscapes across the Southwest. When combined with the infrequent reproduction cycle of shade-intolerant ponderosa pine and safe sites created by windthrows, frequent surface fire produced an ever-shifting spatial mosaic of grass- and forb-covered openings along with patches of regenerating, mature, and old-age ponderosa pine (Pearson 1910, Cooper 1960, White 1985).

Restoring this spatial pattern to its previous condition is vital to the health of the ponderosa pine ecosystem because 1) openings account for the highest level of plant diversity in this ecosystem (Laughlin et al. 2006); 2) the grass component in these openings provides the fuel for the low-severity, surface-level fires that are the essential process in maintaining the ecosystem; 3) the recent increase in ponderosa pine density has occurred at the expense of openings and, therefore, diminishes the health of the ecosystem and its processes; and 4) the historic, clumpy spatial pattern also appears critical to ensuring that there are genetic "neighborhoods" to support a healthy ponderosa pine population (Addicott et al. 1987, DeWald 2003), the growth of large trees (Ronco et al. 1985, Biondi 1996, Ffolliott et al. 2000), and improved wildlife habitat for certain species (Ffolliott et al. 1977, Graham et al. 1994, Waltz and Covington 1999, Wightman and Germaine 2006). Reintroducing a clumpy spatial pattern may also be a key factor in reducing the risk from catastrophic, stand-replacing crown fires (Fulé et al. 2007).

Moving From Overstocked Forests to a Dynamic Ecosystem Pattern

While many policymakers, ecologists, and land managers agree that the number of ponderosa pine in today's southwestern forests must be reduced in order to decrease the potential of catastrophic wildfire and increase diversity within the system, there is limited research and discussion about spatial pattern, what it should look like, and how best to achieve it (although see Cooper 1961, Mast and Wolf 2004, Sanchez-Meador 2006). There are, however, some general ideas about how to proceed.

Perhaps the first thing to recognize is that a one-size-fits-all approach to managing ponderosa pine-dominated landscapes will not work because each stand within a landscape is unique. Moreover, as White and his colleagues (1999) point out, there is a need for site-specific data because disturbance regimes vary even within single vegetation types (see also Brown et al. 2001). This suggests that land managers need to carefully analyze various environmental factors (e.g., soils, topography, climate, microclimate, adjacent vegetative types, wildlife uses, etc.) of a stand as well as its disturbance history in order to better understand its dynamic nature. Studying and analyzing existing historic evidence (openings, snags, stumps, stump holes) is a key way to understand the spatial patterns of southwestern ponderosa pine forests (Friederici 2004, Sanchez-Meador 2006). This type of analysis can be useful in establishing a reference pattern when studied across several stands or patches, and then interpreted in conjunction with soils, topography, and climatic data, such as that found in Terrestrial Ecosystem Surveys. It forms the basis for the kind of treatments suggested by the ERI and others (e.g., Allen et al. 2002). With this information in hand, land managers can then develop restoration prescriptions aimed at restoring a spatial pattern that is consistent with the evolutionary history of the site and meets contemporary fire protection, increased biodiversity, and wildlife enhancement goals.

While the field work of marking, thinning, and/or burning to create a dynamic spatial pattern will likely take place on the stand level, it's important to recognize that these activities are part of a larger scale effort. Integrating landscape- and stand-level goals and objectives is necessary in order to establish the conditions that will create a dynamic mosaic of healthy forests and wildlife habitats that interact as they should with natural processes, such as surface fire, insects, and pathogens. In addition to seeking patterns that will lower the risk of catastrophic fire and increase biodiversity, planners working at the landscape level should consider how stands (patches) will fit together across the landscape to provide corridors and networks of habitat for wide-ranging animal species as well as those that require specific habitat types (Noss and Friederici 2006). Planning a schedule for logical and economically viable thinning of woody material from the forest will also be needed.

Developing a Pattern Language for Restoring Spatial Patterns in Ponderosa Pine

Architect Christopher Alexander's 1977 work, *A Pattern Language*, offers some seminal ideas about how to design building and landscape features for sustainable human use. These basic concepts are: 1) use classic, tested patterns because they are reliable; 2) identify patterns at different scales as well as their hierarchical relationships, and 3) set general rules, but allow for adaption according to circumstances and contexts. While originally written for architects and landscape architects, Alexander's ideas can also be adapted to forest restoration.

Whether planners and designers are ultimately concerned about a building or a clump of trees, they begin by looking at the largest patterns first, which in the case of forest restoration would be at the landscape level. The language of the pattern in such a situation focuses on processes and uses the terminology established by forest ecologists—"shifting mosaic," "dynamic stability," or "mosaic-cycle"—to describe a spatial pattern that operates at that scale. The use of this terminology suggests a forested landscape that is process driven and able to exist in multiple states of vegetative

Clump: A small cluster of trees, typically of similar age and size, sometimes variable ages; interlocking crowns; more or less isolated from adjacent clumps. The Forest Service (Youtz et al. 2008) does not recognize clumps, only groups.

Dynamic: Active, rather than static; changing with time under the influences of natural energetics and processes.

Group: A non-uniform arrangement of clumps and interspaces surrounding by openings; size varies, but typically 0.75 acres or much more; includes uneven-aged trees of various size classes.

Inter-space: A break in the canopy between trees in clumps: relatively small in size; little to no tree regeneration due to frequent fire and shade intolerance of ponderosa pine; no interlocking crowns.

Landscape: A dynamic mosaic of stands representing a sustainable mix of structural stages; 1,000-10,000 acres in size.

Meadow: An opening that is always treeless; not the same as openings or inter-spaces; typically has a high level of herbaceous biodiversity; may have different soil type or soil moisture than opening or inter-space.

Opening: A spatial break between groups of trees; varies in size from 0.08-1.5 acres depending on site conditions; covered with herbaceous vegetation; largely treeless except for snags and clumps of young seedlings or saplings; some large coarse woody debris; kept open by frequent, surface fires.

Patch: A relatively homogeneous area that differs from its surroundings (Forman 1995). Patches are the basic unit of the landscape that change and fluctuate--a process called patch dynamics. Patches have a definite shape and spatial configuration, and can be described compositionally by internal variables such as number of trees, number of tree species, height of trees, or other similar measurements (Forman 1995); similar to a stand.

Stand: A biotic community that includes any number of openings and groups, but possesses sufficient uniformity of composition, age, and spatial arrangement to be distinguishable from adjacent communities or stands.

Figure 1. Pattern language terms for ponderosa pine

structure and composition. From an implementation perspective, there is a recognition that patterns designed at the landscape level require patience and strategic efforts to accomplish; they can never be completed in just one action.

At the stand level, the language of the pattern describes something more like buildings and the spaces between them. Here, the terms—"groups," "clumps," "interspaces," and "openings"—can be used to describe essential elements in the spatial arrangement of the stand (Figure 1). We can also identify these areas in terms of their intended use—for example, "wildlife area," "timber area," "old-growth area," "herbaceous area"—while recognizing that although these uses remain consistent throughout the landscape, their locations may shift depending on disturbance patterns and environmental conditions. In fact, land managers should consider using environmental conditions, as previously described, to set the context for a particular part of the pattern (e.g., large groups oriented perpendicular to the prevailing winds, or distinct clumps and larger openings on basalt soils and less distinct clumps and smaller openings on sedimentary soils) and/or uses (e.g., clumps and snags available for wildlife use by birds of prey, bats, and cavity nesters).

The use of a pattern language also allows land managers to describe the general pattern but remain flexible in how to make the pattern. For instance, by remaining open to the use of various silvicultural and other thinning techniques, managers can, if necessary, modify the stand so as to create a pattern that fits the historical legacy of the stand, allows for the return of key disturbance processes such as frequent surface fire, and helps move the landscape toward a dynamic and resilient state rather than a static one that is susceptible to catastrophic disturbances.

Frequently Asked Questions about Restoring Spatial Patterns in Southwest Ponderosa Pine Forests

1. ***What elements (functions, structure, processes) are needed in order to identify and/or quantify the historic range of variation for a healthy spatial pattern for ponderosa pine?***
   The concept of a historic range of variability (HRV) can help land managers assess and understand the dynamic nature of the stands and landscapes they are working to restore (Morgan et al. 1994, Fulé et al. 1997, Moore et al. 1999, Swetnam et al. 1999, Egan and Howell 2001, Smith 2006). The central idea of an HRV study is to determine how the disturbance processes and/or structural composition of a given stand or landscape operated dynamically over time. The findings of such a study help land mangers identify the frequency, intensity, and spatial scale of key variables within the system. By identifying the HRV of key ecosystem variables, land managers can determine how those variables reacted to disturbance (e.g., how tree density responded to fire frequency).

   In order to establish an HRV for a stand in a southwestern ponderosa pine forest, the following data are useful: fire return interval, tree density/unit area (or basal area), vegetation patterns, at least a qualitative measure of herbaceous biomass, and data about historic animal populations and/or composition (Fulé et al. 1997, Morrison 2001). Table 1 (see page 6) is an example of a HRV data set that identifies pre-European settlement trees per acre at various locations in New Mexico and northern Arizona. If the data are from a reasonably long time period (e.g., a century or more) variables such as those suggested should provide enough intersecting, supporting evidence to identify the HRV. Finally, information obtained either new or existing HRV studies should be integrated with information about the contemporary situation.

Land managers can find out more about techniques for gathering HRV data and how to compile and analyze that data by referring to the ERI Working Paper 7 (Friederici 2004), which contains specific information about establishing reference conditions in southwestern ponderosa pine forests.

2. ***Did the spatial pattern of group and openings shift across the landscape over time?***
   Yes, the spatial pattern of groups and openings did change with time. For example, a tree-dating study of existing and dead trees at Gus Pearson Natural Area (Mast et al. 1999, Fulé and Moore unpublished) shows that younger trees established themselves in clumps and groups at some distance from older trees, growing in what were previously openings. However, this dynamic process took considerable time given the centuries-long life span of ponderosa pine and the vagaries of pine reproduction in the Southwest. Any number of random events (drought, poor seed crop, excessive seed predation, extreme monsoon), regular disturbances (surface fire, freeze-thaw cycles, herbivory), and competition from grasses helped to shape the shifting mosaic of tree groups and openings. Moreover, while they did occur, changes in the ponderosa pine spatial pattern would have been relatively small (i.e., stand size) because ponderosa pine seeds typically disperse within 210 feet on the downwind side and within 60 feet on the upwind side of the parent tree (Pearson 1910).

   Staff from the ERI has gathered anecdotal evidence which suggests that the spatial pattern of ponderosa pine forests may have shifted slightly more on sedimentary soils (limestone, sandstone) than on basalt soils. These observations and other research (Table 1 in this paper, Sanchez-Meador 2006) also indicate that, in general, sedimentary soils tend to produce more trees per acre, larger clumps and groups, and smaller openings (0.08-0.8 acre) relative to those found on basalt soils (0.2-1.5 acre). Variations on this generalization are typically due to site conditions, especially better soils and/or increased soil moisture. For example, data in Table 1 indicates that more presettlement ponderosa pine were found on sites with more available moisture in the Santa Fe National Forest than on sites near Flagstaff, Arizona, despite the fact that basalt is the soil parent material at each of these study sites.

3. ***Can land managers leave existing groups of trees in historical opening while areas that historically contained groups of trees remain treeless? If so, is this still ecological restoration?***
   Where treatment goals and objectives call for optimizing large trees, managers may choose to retain trees that are in former grassland openings. It's important to remember that, in terms of ecological restoration, the critical goal is to restore the spatial pattern and the processes and species composition that support it. That means that groups and openings do not have to be in the same place they were sometime in the past. What it does mean is that land managers are going to start with a close approximation of the historic spatial pattern and set that in motion, allowing it to ebb and flow as it did in the past. If the treatments lead to improved forest health, recovery of the understory, and allows for the safe reintroduction of low-intensity, surface fires then land managers are moving the site from a degraded state to a healthy one. However, managers should take all precautions to maintain existing high-quality and/or even slightly degraded meadow openings or parklands because the biodiversity they contain is difficult, if not impossible, to replace or restore.

4. ***Were historic clumps, groups, and stands even-age or uneven age?***
   The historic southwestern ponderosa pine landscape consisted of uneven-aged stands, uneven-aged groups, and both uneven-aged and even-aged clumps as well as lone trees. For example, a study of ponderosa pine regeneration over several centuries at Gus Pearson Natural Area (Mast et al. 1999, Fulé and Moore unpublished) shows relatively even-age clumps (most clumps had at least two age cohorts) and uneven age groups. The findings also indicate, however, that uneven-age composition in clumps does occur, and that some clumps do have a linear orientation, which suggests that they formed in the organic remains of a fallen tree or snag.

5. ***What evidence is there to demonstrate that pre-European settlement clumps of trees had interlocking crowns even in younger age classes or small-diameter trees? Are such clumps of younger trees sustainable over time?***
   We have evidence from historical photographs, eyewitness accounts, and scientific studies of historical field evidence which indicates that only large ponderosa pines had interlocking crowns prior to or shortly after European settlement. Clumps of smaller trees may have had interlocking crowns for short periods of time, but they were typically thinned out by surface fire, drought, and/or inter-tree competition. Today's smaller trees with interlocking crowns are not a sustainable situation at the scale of a stand or landscape due to effects of competition, fire, drought, and insects. This situation is displayed at Taylor Woods experimental site, near Flagstaff, Arizona, where overstocked, dog-hair stands of ponderosa pine grow very poorly and provide little if any wildlife habitat, while ponderosa pine at lower stocking rates grows vigorously with interlocking crowns where they have been left to grow close enough together.

6. ***The U.S. Forest Service in Region 3 has as its goal a regulated, sustainable uneven-age stand structure. Is this goal necessary or will an unregulated, all-age silivicultural system meet their multiple resource needs?*** Current attempts to achieve forest management goals through the use of VSS classes—a system based on regulated developmental stages rather than a dynamic spatial pattern--are being promoted in order to establish desired critical wildlife habitat (i.e., northern goshawk), to reduce the risk of catastrophic crown fire across the landscape, and to produce a forested landscape that operates within the historic range of variability (Youtz et al. 2008). However, this approach, as generally applied, maintains high forest cover at the stand level at all times and does not allow the pattern dynamics of the forest to naturally occur across the landscape, relying instead on scheduled 20-year cutting cycle (including the removal of large, old trees—VSS6) and prescribed fire on a 10- to 20-year cycle to promote forest regeneration.

   This regulated, scheduled re-entry strategy may not be necessary to achieve the goals of providing goshawk habitat or returning the landscape to conditions within the historic range of variability. Research from the ERI shows that while there are natural temporal gaps in southwestern ponderosa pine regeneration, those gaps are relatively short (30-40 years) and do not jeopardize the sustainability of the southwestern ponderosa pine forests (Mast et al. 1999, Bailey and Covington 2002). Hence, the unregulated ponderosa pine ecosystem was previously sustainable and will likely be that way once forests are appropriately thinned to reconfigure their natural spatial pattern and fire is allowed to return as a natural disturbance process.

Suggested Recommendations

- Forest openings are critical to the proper functioning of ponderosa pine ecosystems. Along with decreasing the number of trees, their recovery should be a central focus of ecological restoration efforts throughout the Southwest.

- Because each stand is unique, the importance of site/stand analysis cannot be emphasized enough. Soils, topography, aspect, and the historic spatial structure of pre-European settlement openings and trees should be analyzed in order to help guide the process of pattern development and restoration.

- Create a spatial pattern that is consistent with the historic evidence on the land, remembering that soil type, topographic aspect, and moisture level play significant roles in determining the size of clumps, groups, and openings.

- Use historic evidence complemented by analysis of the enviro-historical condition of the stand to make decisions about leave trees. While this approach initially involves a short learning curve for tree markers, it provides benefits across the board in terms of meeting the goals and objectives typically part of southwestern forest management plans.

- Where treatment objectives call for maximizing the number of large trees, managers may choose not to retain trees nearest the historic clumps because they may be smaller than trees in former grasslands or openings. That choice is acceptable restoration if retaining the habitat qualities associated with the larger trees is important. However, the decision should not compromise the creation of forest openings or existing, high-diversity or even mildly degraded meadows or parklands.

- Periodic, surface fires—either human-set or from lightning—are the best way to maintain forest openings and restore natural processes. If not burned (or thinned), the openings will fill in with trees and the health of the stand will again become compromised.

- Think in the context of the entire landscape and in long time frames. Ecosystems are dynamic and areas that are now openings may become treed in the future and vice versa. Managers need to take a long-term view of their activities and see their work as putting the ecosystem back in motion again, that is, back within its range of natural variability with a shifting pattern of forest openings and clumps and groups of trees.

Location	Plot Size	Pre-settlement Pipo Trees/Acre	% Slope/ Aspect/ Soil Parent Material	Elevation (feet)	Reference & Date
Prescott NF, Spruce Ridge 2005	10 Acres	11	W and steep, granite	7,100	Denton, Lund, Bedell
Prescott NF, Hassayampa Lake 2005	10.0 acres	11	Generally SE and steep, granite	7,000	Denton, Lund, Bedell
Coconino NF, Bar-M Study Area 1991	Seventy 0.62-acre plots	23	Gently rolling, basalt	6,800-7,200	Covington and Moore 1992
Gus Pearson Natural Area 1993	7.9 acres	24	Flat, E aspect, basalt	7,500	Mast et al. 1999
Apache-Sitgreaves (Eager South) 2005	10.5 acres	24	Variable, basalt	7,800	Denton, Lund
Camp Navajo, W. of Flagstaff	62 plots across 1,378 acres	26	Gently rolling, includes Volunteer Mt., basalt	7,100-8,000	Fulé, Covington, and Moore 1997
East Fork, Jemez RD-Santa Fe NF. 2005	7.8 acres	45	Flat, basalt	7,800-7,900	Tutten, Lund
Redondo, Jemez RD-Santa Fe NF 2005	11.3 acres	56	Rolling, basalt	7,700-7,900	Smith
Kaibab NF, Goshawk Unit #25 2005	Two 5-acre plots	22-24	Flat, limestone	6,700	Smith, Lund, Denton, Bedell
Cibola NF, NM 2005	2.4 acres	24	Gentle, limestone	Unavailable	Denton, Bedell, Lund
North Kaibab, Kaibab NF 2007	Six 5-acre plots	46-74	Flat, limestone	7,300-7,500	Tutten
North Kaibab NF, 1991	46, 0.62-acre plots.	56	14-40% slope, limestone	6,800-7,800	Covington and Moore 1992

Table 1. Pre-European Ponderosa Pine Trees per Acre at Sites in Northern Arizona and New Mexico

Pre-European settlement trees per acre include both live and dead evidence. Basalt soils are typically moderately deep to deep, fine-textured soils with varying concentrations of rock on the surface and within the soil profile. Granitic soils are typically shallow to moderately deep, coarse-textured soils with high rock content on surface and in profile. Limestone soils are typically moderately deep to deep, fine-textured soils. Surface horizons textures range from loam to clay loam with normally 15- to 35-percent rock content. Subsurface horizon is typically clay. Denton, Smith, Lund, and Bedell are, or were, members of the ERI Agency Outreach Team; Tutten is an ERI research associate.

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Working Papers in Southwestern Ponderosa Pine Forest Restoration

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Reviewed by W. Wallace Covington, Charles Denton, Pete Fulé, Dennis Lund, Steve Rosenstock, Diane Vosick
Series Editor: Dave Egan

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