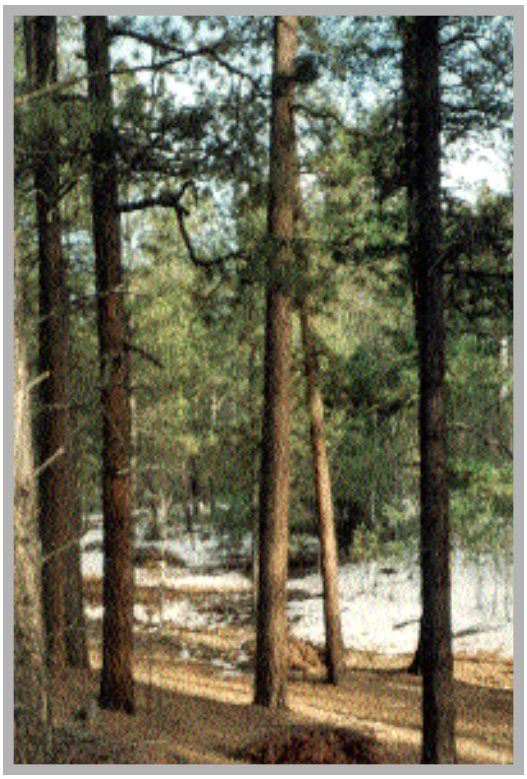
# Fuel Reduction Projects in Southwest Ponderosa Pine Forests

## A Description of Sites and Treatments

by Martha Schumann



**National Community Forestry Center**
Southwest Region Working Paper 9

June 2004

## Chapter 1: Introduction

Public attention and federal resources are focused on reducing fuel loads on forest lands through the National Fire Plan. Forest managers and the public are interested in learning about the range of forest conditions that receive treatment, as well as the range of prescriptions being applied. We developed this study to survey prescriptions and treatment effects in ponderosa pine forests of the Southwest.

Little of the currently available research provides information that can directly inform the design and implementation of fuel-reduction prescriptions in forests. A common purpose of fuel reduction projects in ponderosa pine forests is to create a fuel structure that will not support a crown fire. Fire managers operate with two assumptions: that changing fuel structures will 1) change fire behavior and 2) reduce fire severity.

The assumption that mechanically reducing fuels changes fire behavior has been tested using fire behavior models. Thinning can reduce rate of spread (Stephens 1998; Scott 1998) and incidence of crowning (van Wagtendonk 1996). Treating ladder fuels can also reduce fireline intensity (Graves and Nueschwander 1999) and flame lengths (Reinhardt and Ryan 1998).

Research by Pollet and Omi (2002) and Martinson and Omi (2002) demonstrate that mechanical fuel reduction can reduce wildfire severity in ecosystems with frequent, low-intensity fire regimes such as ponderosa pine forests. Research using fire behavior simulation models show reduced fireline intensity and lower scorch height after thinning (Stephens 1988). Treating ladder fuels can also reduce scorch height (Graves and Nueschwander 1999).

Because support for the hypothesis that fuel reduction will reduce the occurrence and extent of crown fires is limited (Cram and Baker. 2002; Pollet and Omi. 2002), land managers, fire management officers, foresters, and scientists are working together to test this hypothesis. This project provides another perspective on informing prescriptions, one that is based on observations from applied prescriptions.

The objective of this project is to describe mechanical fuel reduction treatments implemented in ponderosa pine forests in New Mexico, Arizona, and Colorado. Data were collected to answer three questions:

- What is the range of forest conditions prior to fuel reduction treatments?
- What are the prescriptions used in fuel reduction prescriptions?
- What is the range of forest conditions after fuel reduction treatments?

## Chapter 2: Research Approach

Development of this study stemmed from the growing awareness and interest in wildfire and fuel reduction projects. The research objective came from forest-dependent communities, forest land owners, and public and private land managers.

We used the descriptive method to address the research objective (Isaac and Michael 1981). We chose this research method because it was most effective at answering the questions we heard from the public. Sites of interest were described systematically using data, photographs, observations and site-related documents. With these tools, sites are factually and accurately described.

The descriptive approach captures the variability of sites receiving treatment and the variability of prescriptions implemented at sites, thereby showing a wide range of projects across the region. Describing fewer sites more intensively with tighter selection criteria would have resulted in higher resolution data, but fewer sites. Like a survey study, descriptive research enables comparisons to be made among the sites (Isaac and Michael 1981). However, descriptive research does not necessarily seek to explain relationships or test hypotheses (Isaac and Michael 1981).

### Research Methods

The first step in beginning this project was to select sites to visit. Projects were focused on ponderosa pine forests, the forest type where the majority of fuel reduction treatments are occurring in the southwest. Projects were chosen for geographic variability, located in Arizona, Colorado, and New Mexico to describe projects throughout the region. The majority of sites chosen were on national forests, where significant resources are spent to reduce fuels. However, a project on private land was also profiled. The focus of all treatments was to reduce fuels in projects that were located more than 1/4 mile from structures. We were not interested in projects that created defensible space around buildings. The projects chosen vary in terms of their proximity to urban area or resources that needed protection from wildfires. Some projects profiled stated restoration as their primary objective, while the majority of projects focused simply on fuel reduction.

### Field Data Collection

Sites were not chosen randomly, rather they were selected based on availability. For example, projects needed to be "NEPA-ready," meaning that the environmental analysis on the project had been completed. The original intent of the project was to collect data before and after treatment. However, logistical challenges shifted the project to collect data on areas that had been treated and adjacent areas that were left untreated.

Project size was not one of the selection criteria for study sites. Some projects are small (60 acres) while others are larger in scope (10,000 acres). Large projects are generally broken into multiple treatment units; in this case information is gathered for a single unit.

Stands within each project area were categorized as "treated" or "untreated." "Treated" is defined as an area where trees had been cut, whereas "untreated" is defined as an area where trees had not been cut. An untreated adjacent stand was suitable as a comparison to the treated stand if it was the same forest type and similar management history.

Plots were established within a project area to capture the range of variability of forest conditions within the unit. Plots were located by walking through a site and selecting areas that represented forest conditions of the site. For example, at a site with both dense and open areas, plots were located in both areas. This method of plot establishment captures the range of variability of conditions, but not the proportion of each condition within the unit.

The number of plots established at each site ranged from 3 to 6 in both the control and treated areas. Photos were taken from each plot center and basic quantitative and qualitative information was recorded. In the Appendix, the variables measured are defined and the rationale for choosing these variables is explained.

**Quantitative Data**

Tenth-acre circular plots were established to measure adult trees (>5 inches). The following information was collected for each live adult tree: species, diameter at breast height (dbh), crown base height, crown class (dominant, co-dominant, intermediate, suppressed), and condition (healthy, stressed, dying). The diameter and species of dead trees (snags) was also recorded. Crown base height was measured on a few trees within the plot. These measurements were used to estimate the crown base height on the remaining trees. Because not all trees were measured, crown base height is reported in categories: 0-5, 6-10, 11-15, 16-20, 21-25, and 26 + feet. Aspect and slope were also recorded at each plot location.

One-fiftieth acre circular plots were established at the same plot center to measure saplings (<5 inches dbh) and seedlings (<1 inch dbh). Species, diameter, and condition were recorded for each sapling. The number of trees by species was recorded for seedlings.

Percent canopy cover was measured using a 100 foot transect and a siting tube (Savage 2002). Canopy cover was recorded as present or absent at every four feet along the transect. This is a quick low-tech method for estimating canopy cover.

**Qualitative Data**

Within the tenth acre plot, a number of qualitative variables were recorded:

- ground cover (percent of the area of the ground covered by grass and forbs or litter);
- understory condition (dense, patchy, or open due to presence of saplings, seedlings and shrubs);
- litter layer (depth of needles, dead leaves, dead grass, dead forbs, dead and down branches and boles);
- large (>3 inches) woody debris (classified as abundant, sparse, or absent);
- small (<3 inches) woody debris (classified as abundant, sparse, or absent).

A photo-series developed for quantifying dead and down fuel loads in ponderosa pine forests was used to provide information about fuels.

Paired photos facilitate comparison of conditions, although photos are not paired before- and after-treatment (i.e., even though conditions resemble one another they are not of the same place). Paired photos are not used when the treated and untreated areas are poor comparisons. Single photos are used to illustrate a certain point.

Prescriptions for each site are included. The prescriptions reflect the wide variety in the information provided by the land manager. In all cases, the original format of the prescription is retained. However, in some cases grammatical changes were made to make the prescriptions more readable. If a prescription is brief, the entire prescription is included without editing of the content. All prescriptions presented reflect the level of detail in the prescription used for a project.

The longer prescriptions were edited for clarity and format. Every effort was made to reflect the content of the prescription provided by the land manager. Prescriptions are written in the present tense, as if they are marking guidelines.

## Chapter 3: Treatments

Treatments in this chapter are described by location, prescription, size, status, implementation method, data, photographs, and site observations. Photographs are generally presented in pairs of untreated and treated sites. This approach was chosen to facilitate describing changes in forest characteristics. Two of the sites, the Pritzlaf Ranch and Ruedas thinning project, include photos taken before and after treatment.

Treatments are organized in the following manner. Three restoration projects are grouped together and are profiled first. The second grouping describes fuel reduction projects. In both categories, restoration and fuel reduction, projects are ordered by tree density in untreated stands, beginning with sites with the highest tree density first (Table 1). Any single variable, considered alone, does not adequately describe forest conditions. However, we felt that some ordering of sites would assist in the reader in making comparisons among sites.

**Table 1: Summary Data for All Sites**

| SITE | DENSITY (trees per acre) | | BASAL AREA (square feet per acre) | | AVERAGE DIAMETER (inches) | | CANOPY CLOSURE (percent) | |
|---|---|---|---|---|---|---|---|---|
| | untreated | treated | untreated | treated | untreated | treated | untreated | treated |
| **Restoration** | | | | | | | | |
| Fort Valley Restoration | 148 | 78 | 181 | 90 | 14.3 | 15.7 | 54 | 22 |
| Beaver Railroad Restoration | 148 | 43 | 218 | 66 | 11.9 | 16.9 | n/a | 25 |
| Colt Restoration | 145 | 35 | 140 | 57 | 12.6 | 17.7 | 43 | 28 |
| **Fuel Reduction** | | | | | | | | |
| Los Alamos National Lab | 407 | 90 | 252 | 56 | 9.5 | 10.6 | 53 | 19 |
| Pritzlaf Ranch | 234 | 110 | 98 | 52 | 9.7 | 12 | n/a | 33 |
| Santa Fe Watershed | 230 | 80 | 101 | 88 | 9 | 14.5 | 49 | 44 |
| David Canyon | 215 | 65 | 102 | 71 | 8.7 | 13.5 | 49 | 26 |
| Ruedas | 210 | 100 | 100 | 58 | 9 | 10 | 49 | 28 |
| Dollar | 207 | 113 | 161 | 115 | 11.1 | 13.2 | 39 | 36 |
| Colt Commercial Thin | 203 | 43 | 213 | 91 | 12.9 | 17.4 | 33 | 9 |
| Spring Valley | 202 | 88 | 187 | 93 | 13.2 | 14.1 | 54 | 34 |
| Bruno Tank | 84 | 110 | 131 | 78 | 16.8 | 11.7 | 58 | 22 |

**Project:** **Fort Valley**

**Location:** Arizona, Coconino National Forest, Peaks Ranger District

**Project Size:** 25 acres

**Prescription:** The prescription for the Fort Valley project was derived from the presettlement model (Covington & Moore 1994; Covington et al. 1997) and is briefly summarized below. The objective of the presettlement model is to restore historic ponderosa pine forest structure, recreating as far as possible the density, spatial arrangement, and variability of trees at the time of disruption of the frequent fire regime (1870-1890) (Covington and Moore. 1994). The specific prescription used in this unit of the Fort Valley project is "modified restoration with 20% deferral for wildlife management."

The first step in following the presettlement model is to search the stand for evidence of presettlement trees, such as stumps, snags, dead and downed trees, or stump holes. A specified number of replacement trees are retained for all dead presettlement trees. Thus, residual tree density and spacing is based on the evidence of presettlement trees and the size of the trees within the stand. At this site, no old growth trees or yellow bark ponderosa pine or trees greater than 16 inches are removed from the area.

Modified restoration with deferral for wildlife management means that 20% of the treatment area will not be cut. The patches selected for deferral will generally be the densest. The areas identified within the area for this treatment are part of a network of wildlife cover and travelways. Cover is designed to occur in variable sized patches to lay mostly in a southeast to northwest pattern (across the prevailing severe fire weather wind pattern for maximum protection of leave strips).

Pile approximately 80% of the slash. Burn or remove slash piles from the site. Apply prescribed fire following the removal of the piles.

**Status:** Slash treatment and wood removal was underway during the time photos and plots were taken.

**Implementation:** Stewardship contract, machine harvesting with feller-buncher and forwarder.

## Photos: Fort Valley

**A.**
*The opening in the foreground of the untreated area is mimicked in the opening created in the treated area. Note that the density of the trees in the background of the treated area has been reduced.*


Untreated


Treated

**B.**
*Fewer small diameter trees are present in the treated area compared with the untreated area.*


Untreated


Treated

**C.**
*In some cases small diameter trees were left in the stand, as seen in the center of the treated area, to help recreate presettlement tree spacing.*


Untreated


Treated

**Table 2: Fort Valley**

| | Untreated | Treated |
|---|---|---|
| Trees | | |
| Species Composition: *Ponderosa Pine* | 100% | 100% |
| Live Trees per acre | 148 | 78 |
| Basal Area | 181 $ft^2$/acre | 90 $ft^2$/acre |
| Average Diameter of Adult Trees | 14.3 in | 15.7 in |
| Condition: *healthy* | 83% | 100% |
| *stressed* | 17% | 0 |
| *dying* | 0 | 0 |
| Canopy Characteristics | | |
| % Canopy Closure | 54% | 22% |
| Average Crown Base Height | 21-25 ft | >25 ft |
| Crown Base Height of the Lowest 20% | 11-15 ft | >25 ft |
| Crown Class: *dominant* | 31% | 13% |
| *co-dominant* | 23% | 59% |
| *intermediate* | 21% | 28% |
| *suppressed* | 25% | 0 |
| Regeneration | | |
| Saplings per acre | 13 | 13 |
| Seedlings per acre | 0 | 0 |
| Number of Plots | 4 | 4 |

**Observations:** **Fort Valley**

The prescription reduced both density and basal area by about half, reflecting broad objectives implicit in the prescription. The average diameter in the treated site was only slightly higher than in the untreated site. Average tree health is better in the treated area where stressed trees have been removed.

Average crown base height was higher in the treated area than in the untreated area. In addition to low branches, small trees provide ladder fuels, as seen in the center of the untreated site in photo B. Raising the crown base height and reducing ladder fuels will facilitate the reintroduction of surface fire.

Percent canopy closure in the treated area was much lower than in the untreated area. This is due to the fact that small diameter trees were chosen as leave trees in some cases. Small diameter trees have smaller crowns, contributing to a low percent canopy cover.

The arrangement of trees within the site was variable, guided by locating evidence of pre-settlement forest structures. This method succeeded in creating a stand with open patches and clumps of trees, in what could have otherwise been a stand with relatively uniform tree spacing.

One limitation of this method is that the arrangement of trees in a forest stand is guided by recreating a particular spacing, rather than using the best existing forest structure to decide which trees to cut and which to leave.

Approximately twenty percent of the slash was left on site. This allows nutrients stored in slash to remain within the system, whereas complete removal of slash can deplete the nutrient levels of a site. The majority of the slash, however, was removed before prescribed burning because high amounts of surface fuels created from slash can lead to intense surface fires.

**Project:** **Beaver Railroad Restoration**

**Location:** Colorado, San Juan National Forest, Dolores R.D.

**Prescription:** This prescription was also used for the Colt Restoration project (page 18).

1. Reduce current stand densities to pre-1870 conditions (post-treatment 45-55 BA; clumpy distribution).
2. Increase average stand diameters (post-treatment average 14" dbh or larger), create a clumpy distribution, accentuating uneven-aged character.
3. Increase crown base height by 20% or more.
4. Reduce cover of woody plants (e.g. Gambel oak) and detritus (litter and woody debris). The canopy cover percent of Gambel oaks should be reduced by 10-30%, the depth of litter layer should be reduced to less than 1", and the quantity of 1 to 10 hour fuels should be less than pre-harvest conditions.
5. Reduce down woody fuels. The tons/acre of 100-hour fuels should be below pre-harvest conditions.
6. Increase cover and diversity of native herbaceous plants and increase pine reproduction. There should be measurable change in richness and cover of herbaceous plants. Pine regeneration should occur within 20 years at a rate of 50 seedlings and saplings per acre.
7. Increase habitat diversity on a landscape scale. Leave clumps of trees up to 3/4 acres in size. Create openings up to 1/2 acre in size. Create more open stand structures in the widespread second growth ponderosa pine type, manage for two or more snags per acre, reduce conifer competition around the scarce inclusions of aspen, protect pinyon pine, juniper, and Douglas-fir where found, and save clumps of oakbrush where average stem diameter is 3 inches or greater.
8. Increase the frequency of low intensity fire disturbance including some level of summer fire. Prescribe burn twice within 10 years post-harvest, third burn within 20 years. At least one burn should occur during the height of the growing season.
9. Save all snags
10. Leave all trees with old growth attributes (yellow platey bark and flat topped crowns).

Restoration prescription indicators established by the San Juan National Forest in 1997. Note: The Dolores RD used a restoration prescription because there were many trees over 14" diameter.

**Project Size:** The Beaver Railroad restoration project is comprised of multiple units. The units in which data were collected were adjacent to one another. The untreated area was approximately 15 acres in size, the treated area was approximately 20 acres in size.

**Status:** Thinning, wood removal, and slash disposal is complete. Prescribed burning planned.

**Implementation:** Implementation: Timber Sale

## Photos: Beaver Railroad Restoration

**A.**
*Small natural openings exist in the untreated area. To mimic these, openings were created in the treated site, increasing cover and diversity of grasses and herbaceous plants.*


Untreated


Treated

**B.**
*Thinning focused on reducing the number of small diameter trees, as shown in the photo of the untreated site. The density of small diameter trees is lower in the treated stand.*


Untreated


Treated

**Table 3: Beaver Railroad Restoration**

| | Untreated | Treated |
|---|---|---|
| Trees | | |
| Species Composition: *Ponderosa Pine* | 100% | 100% |
| Live Trees per acre | 148 | 43 |
| Basal Area | 218 $ft^2$/acre | 66 $ft^2$/acre |
| Average Diameter of Adult Trees | 11.9 in | 16.9 in |
| Condition: *healthy* | 65% | 85% |
| *stressed* | 35% | 15% |
| *dying* | 0 | 0 |
| Canopy Characteristics | | |
| % Canopy Closure | N/A | 25% |
| Average Crown Base Height | 21-25 ft | 16-20 ft |
| Crown Base Height of the Lowest 20% | 11-15 ft | 11-15 ft |
| Crown Class: *dominant* | 19% | 64% |
| *co-dominant* | 30% | 12% |
| *intermediate* | 30% | 12% |
| *suppressed* | 21% | 12% |
| Regeneration | | |
| Saplings per acre | 38 | 8 |
| Seedlings per acre | 0 | 0 |
| Number of Plots | 4 | 6 |

**Observations: Beaver Railroad Restoration**

The Beaver Railroad project attempts to restore the forest to conditions that can support low-intensity surface fires and resemble historic structure. The prescription is highly detailed, providing direction for how to achieve the desired structure.

The treatment significantly reduced the basal area and tree density, compared with much higher values in the untreated stand. Average basal area in the treated stand (66 $ft^2$/acre) was slightly higher than the target value (45-55 $ft^2$/acre).

Because small trees were removed in the treated site, the average diameter in the treated area was 16.9", compared with an average diameter of 11.9" in the untreated area. Larger, healthier trees were chosen as leave trees; this is reflected in the values for crown classes and condition classes. The average crown base height was not raised, which is anomalous, considering the crown and condition class data.

The prescription for the Beaver Railroad site calls for increasing habitat diversity on a landscape scale. One way this is accomplished is by creating openings up to 1/2 acre in size, and by creating more open stand structures in the second growth ponderosa pine type. In addition to increasing habitat diversity, openings break up continuous canopy cover and therefore reduces the risk of crown fire spread (Scott and Reinhardt 2001). Tree spacing was also diversified by leaving denser clumps of trees. As a result of these guidelines, spatial diversity was present in the treated site, with large openings in the canopy and dense patches with interlocking tree crowns. Photos A and B of the treated stand depict a healthy understory that has benefited from an increase in sunlight from canopy openings.

One goal stated in the prescription is to create a stand with trees of multiple ages, commonly referred to as "uneven-aged" character. To accomplish this, the prescription specifies desired regeneration rates and levels. This is the only prescription that included regeneration targets.

The prescription specified acceptable levels of slash after treatment, quantified in tons per acre. Slash levels in the treated site were low. In spite of the commercial nature of the project and the slash treatment, ground disturbance from logging was minimal.

Forest managers are increasingly using prescribed fire to restore the natural effects of fire and accomplish fuel reduction goals. Prescribed fire has multiple benefits, including killing over-abundant seedlings and small trees, reducing slash after harvesting, increasing nutrient cycling, and enhancing understory vegetation. Research conducted at the Beaver Railroad site concluded that prescribed burning is necessary to reach restoration goals, for example increasing understory plant diversity (Lynch et al. 2000).

**Project:** **Colt Restoration**

**Location:** Colorado, San Juan National Forest, Dolores R.D.

**Prescription:** This prescription was also used for the Beaver Railroad Restoration project (page 14).

Restoration prescription indicators established by the San Juan National Forest in 1997:

1. Reduce current stand densities to pre-1870 conditions (a post-treatment basal area of 45-55 $ft^2$/acre; distributed in a clumpy manner).
2. Increase average stand diameters (post-treatment average 14" dbh or larger), create a clumpy distribution, accentuating uneven-aged character.
3. Increase crown base height by 20% or more.
4. Reduce cover of woody plants (e.g. Gambel oak) and detritus (litter and woody debris). The canopy cover percent of Gambel oaks should be reduced by 10-30%, the depth of litter layer should be reduced to less than 1", and the quantity of 1 to 10 hour fuels should be less than pre-harvest conditions.
5. Reduce down woody fuels. The tons/acre of 100-hour fuels should be below pre-harvest conditions.
6. Increase cover and diversity of native herbaceous plants and increase pine reproduction. There should be measurable change in richness and cover of herbaceous plants. Pine regeneration should occur within 20 years at a rate of 50 seedlings and saplings per acre.
7. Increase habitat diversity on a landscape scale. Leave clumps of trees up to 3/4 acres in size. Create openings up to 1/2 acre in size. Create more open stand structures in the widespread second growth ponderosa pine type, manage for two or more snags per acre, reduce conifer competition around the scarce inclusions of aspen, protect pinyon pine, juniper, and Douglas-fir where found, and save clumps of oakbrush where average stem diameter is 3 inches or greater.
8. Increase the frequency of low intensity fire disturbance including some level of summer fire. Prescribe burn twice within 10 years post-harvest, third burn within 20 years. At least one burn should occur during the height of the growing season.
9. Save all snags
10. Leave all trees with old growth attributes (yellow platey bark and flat topped crowns).

**Project Size:** The treated unit is approximately 25 acres in size. The adjacent untreated unit is approximately 15 acres in size.

**Status:** Thinning, wood removal, and slash disposal is complete. Prescribed burning planned.

**Implementation:** Timber Sale

## Photos: Colt Restoration

**A.**
*Natural openings exist in the untreated area. Large openings were created through harvesting in the treated site.*


Untreated


Treated

**B.**
*Small diameter trees, such as those shown in the photo of the untreated area , were removed in the treated area.*


Untreated


Treated

**C.**
*Density of trees is higher in the untreated site than in the treated site.*


Untreated


Treated

**Table 4: Colt Restoration**

| | Untreated | Treated |
|---|---|---|
| Trees | | |
| Species Composition: *Ponderosa Pine* | 100% | 100% |
| *Aspen* | 2% | 0 |
| Live Trees per acre | 145 | 35 |
| Basal Area | 140 $ft^2$/acre | 57 $ft^2$/acre |
| Average Diameter of Adult Trees | 12.6 in | 17.7 in |
| Condition: *healthy* | 84% | 100% |
| *stressed* | 14% | 0 |
| *dying* | 0 | 0 |
| Canopy Characteristics | | |
| % Canopy Closure | 43% | 28% |
| Average Crown Base Height | 21-25 ft | 21-25 ft |
| Crown Base Height of the Lowest 20% | 16-20 ft | 16-20 ft |
| Crown Class: *dominant* | 26% | 89% |
| *co-dominant* | 32% | 0 |
| *intermediate* | 12% | 4% |
| *suppressed* | 30% | 4% |
| Regeneration | | |
| Saplings per acre | 17 | 0 |
| Seedlings per acre | 67 | 0 |
| Number of Plots | 4 | 4 |

**Observations: Colt Restoration**

Following the direction of the prescription, basal area is lower in the treated site than in the untreated site. Note that the average basal area in the treated site (57 $ft^2$/acre) is higher than the target basal area (45-55 $ft^2$/acre). This suggests that not as much basal area was removed as prescribed. This "thinning from below" resulted in a high average diameter in the treated site (17.7"), compared with the average diameter in the untreated site (12.6"), also a goal of the prescription. The average crown base height in the treated area (21-25 feet) was not higher than in the untreated area (21-25 feet). The majority of trees in the untreated area did not have low branches.

The trees remaining after thinning were healthy and in the dominant crown class. It is the presence of these healthy, large-diameter, dominant trees that help restore historic forest structure. This first thinning entry is a first step towards restoring historic structure and processes, such as fire.

Spatial diversity was present in the treated site, with large openings in the canopy (photos A) and areas with a high density of trees. Harvest-created openings help increase the diversity of forest structure within a stand. The space created by openings contrasts with residual clumps and groups of trees.

In forests where the numbers of seedlings and saplings are low, prescriptions may try to create favorable conditions for their recruitment. The Pines Project restoration sites (Beaver Railroad and Colt) try to create a stand with trees of multiple ages, commonly referred to as "uneven-aged" character. To accomplish this, the prescription states, "pine regeneration should occur within 20 years at a rate of 50 seedlings and saplings per acre." Regeneration is currently lacking in the treated site.

Note: The Dolores Ranger District used a restoration prescription because there were many trees over 14" diameter. The Colt Thinning project was treated using a commercial thinning prescription (page 46), because there were fewer large trees. The rationale is that it is difficult to ‘restore” historic forest structure in a primarily even-aged stand with small diameter trees. The silviculturist determines whether a stand is suitable for a restoration or thinning prescription based on stand-examine data.

**Project:** **Los Alamos National Laboratory (LANL)**

**Location:** Los Alamos, New Mexico

**Prescription:** Thin ponderosa pine stand to fall within the following parameters.

Separate individual tree crowns by a distance of 10 to 25 feet. Separate crowns between clumps of trees by a distance of 30 to 40 feet.

Reduce tree density to between 50 to 150 trees per acre. Reduce ladder fuels by primarily thinning smaller trees that allow fire to move from the ground into the tree crowns. Target trees <9" diameter for removal. Remove trees in the larger size classes if necessary to achieve the desired spacing.

Do not remove existing large snags (>12"dbh) except in cases where people and property are directly threatened. Preferentially remove diseased, malformed, or weakened trees during thinning treatments.

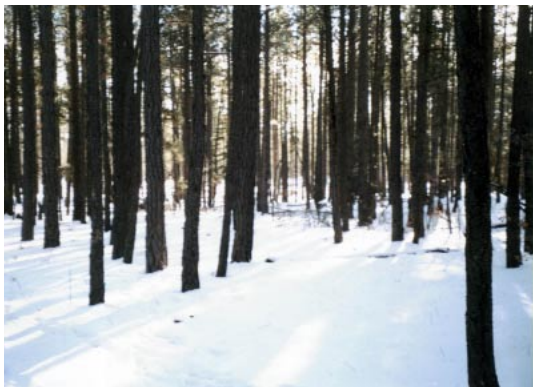
**Project Size:** Stands sampled are approximately 3 acres untreated and 10 acres treated.

**Status:** In the sampled stands treatment is complete.

**Implementation:** Machine skidding. Slash mechanically removed from site and burned at a landing in an air current destructor, a type of open-air incinerator. An air current destructor drastically reduced emissions from burning and operated even when fire risk in the area was high.

**Photos:** **Los Alamos National Laboratory**

**A.**
*Tree density and basal area were much lower in the treated area than in the untreated area.*


Untreated


Treated

**B.**
*This pair of photos shows that in some cases, small diameter trees were left in the treated area, even though the prescription focused on removing trees <9' dbh.*


Treated


Treated

**C.**
*Canopy cover was dramatically reduced in this treated area. Note the lack of shading from tree crowns on the snow.*


Treated

**Table: 5 Los Alamos National Laboratory**

| | Untreated | Treated |
|---|---|---|
| Trees | | |
| Species Composition: *Ponderosa Pine* | 100% | 100% |
| Live Trees per acre | 407 | 90 |
| Basal Area | 252 $ft^2$/acre | 56 $ft^2$/acre |
| Average Diameter of Adult Trees | 9.5 in | 10.6 in |
| Condition: *healthy* | 55% | 96% |
| *stressed* | 41% | 0 |
| *dying* | 4% | 4% |
| Canopy Characteristics | | |
| % Canopy Closure | 53% | 19% |
| Average Crown Base Height | >25 ft | >25 ft |
| Crown Base Height of the Lowest 20% | >25 ft | >25 ft |
| Crown Class: *dominant* | 15% | 21% |
| *co-dominant* | 37% | 69% |
| *intermediate* | 22% | 10% |
| *suppressed* | 26% | 0 |
| Regeneration | | |
| Saplings per acre | 50 | 0 |
| Seedlings per acre | 0 | 0 |
| Number of Plots | 3 | 3 |

**Observations: Los Alamos National Laboratory**

The project accomplished it's objectives; basal area and tree density were dramatically reduced in the project area. Given the nature of the work conducted at Los Alamos (e.g. nuclear technology development) and the recent wildfire in the area (Cerro Grande fire of 2000), it is not surprising that the treatment significantly changed forest structure.

The first photo pair (A) illustrates the significant reduction in tree density in the treated stand. In the photo of the untreated stand, the tree stems obscure the background, whereas in the treated stand it is possible to look through to the background. Prescriptions for fuel treatments often specify wide spacing between tree crowns in order to slow or inhibit the spread of a crown fire, particularly in projects designed to create defensible space. Average tree density in the treated area (90 trees per acre) fell in the middle of the wide range specified in the prescription (50 to 150 trees per acre).

The canopy has been opened significantly in the treated area, dropping from 53% to 19%. Ponderosa pine trees that develop in dense conditions usually have small crowns. Thus, because the crown size of residual trees is small, and tree density was significantly reduced, the canopy cover is low in the treated area (photo pair C).

The prescription and treatment focused on removing small diameter trees and predictably, the treated area has fewer trees in the intermediate and suppressed crown classes. In addition, a higher percentage of healthy trees exist in the treated area (96%) than in the untreated area (55%). This result corresponds with an objective stated in the prescription, to preferentially remove diseased and weakened trees.

The stand prior to treatment shaped the outcome of thinning. The tree spacing in the untreated stand is generally uniform. The stand was composed of similarly sized trees, most likely with similar ages, having all regenerated around the same time. The treatment attempted to leave patches with variable tree density. Clumps of trees with interlocking crowns were uncommon. Differences in tree density and arrangement were not noticeable within the treated area, with the exception of openings. Typically the outcome of thinning in a stand with evenly spaced trees is a uniform stand with wider spacing than before. This site is an example of the difficulty in taking a uniform stand and creating a more diverse forest structure, while also achieving fuel reduction objectives.

The untreated area adjacent to the treated area was not thinned, leaving a dense group of trees. This area serves several functions. It provides cover for wildlife species and increases habitat diversity. The untreated area also offers a comparison to the treated site. Ecologists at LANL are conducting research on the environmental conditions, such as humidity and windspeed levels, beneath the closed canopy in contrast with a much more open forest canopy.

Although three inches of snow cover obscures the ground, the photos illustrate that slash was completely removed from the site, greatly reducing the fuel load on the site after treatment. The prompt removal of slash from this site meant that fire risk did not increase in the short-term (i.e. in the window after thinning but before slash treatment).

**Project:** **Pritzlaf Ranch**

**Location:** Pritzlaf Ranch, San Ignacio, New Mexico

**Prescription:** Create a residual basal area of 80 $ft^2$/acre, with a clumpy distribution. Leave a designated uncut area within the thinning unit for wildlife shelter. Thin the area adjacent to the wildlife leave area (100-150 feet) to a basal area of 60 $ft^2$/acre. Do not cut trees over 12 inches.

Save all snags. Additional snags will be created after the prescribed burn.

Prescribe burn area after treatment.

**Project Size:** The unit is 125 acres in size.

**Status:** Thinning is complete. Wood removal and slash disposal was underway. Prescribed burning planned.

**Implementation:** Hand thinning.

## Photos: Pritzlaf Ranch

**A.**
*Thinning reduced the number of small trees.*


Pre-Treatment


Post-Treatment

**B.**
*Small diameter trees present in the center of the pre-treatment photograph have been removed. Note the absence of small diameter trees in the post-treatment photo.*


Pre-Treatment


Post-Treatment

**C.**
*One objective of the prescription was to reclaim a meadow where trees had encroached. Trees were removed to open up the meadow. In the post-treatment photo note the absence of small ponderosa pines in the meadow.*


Pre-Treatment


Post-Treatment

**Table: 6 Pritzlaf Ranch**

| | Pre-Treatment | Post Treatment |
|---|---|---|
| Trees | | |
| Species Composition: *Ponderosa Pine* | 96% | 100% |
| *Douglas Fir* | 1% | 0 |
| *Gambel Oak* | 3% | 0 |
| Live Trees per acre | 234 | 110 |
| Basal Area | 98 $ft^2$/acre | 52 $ft^2$/acre |
| Average Diameter of Adult Trees | 9.7 in | 12 in |
| Condition: *healthy* | n/a | 93% |
| *stressed* | n/a | 7% |
| *dying* | n/a | 0% |
| Canopy Characteristics | | |
| % Canopy closure | n/a | 33% |
| Average Crown Base Height | n/a | 21-25 ft |
| Crown Base Height of the Lowest 20% | n/a | 16-20 ft |
| Crown Class: *dominant* | n/a | 48% |
| *co-dominant* | n/a | 31% |
| *intermediate* | n/a | 19% |
| *suppressed* | n/a | 2% |
| Regeneration | | |
| Saplings per acre | 240 | 50 |
| Seedlings per acre | 210 | 80 |
| Number of Plots | 5 | 5 |

**Observations: Pritzlaf Ranch**

This is the only site with pre- and post-treatment data. Only a subset of pre-treatment data was collected. The post-treatment data show that the average basal area (52 $ft^2$/acre) is lower than the target of 80 $ft^2$/acre. Tree density was reduced by half, from 234 to 110 trees. Overall, the density of trees varied throughout the treated area, with lowest tree density in the meadow and highest tree density in the uncut area. Restoring the open conditions within the existing meadow increases the horizontal diversity within the forest. This project was successful in creating a range of forest condition throughout the treated area.

Creating habitat to support wildlife populations was a goal of the treatment. The prescription also specifies leaving snags, an important structural component in the forest for a number of wildlife species. Snags were present throughout the stand after thinning.

Stand age appeared to be uniform. There were few large diameter trees present on the site. However, the average diameter of trees was higher after treatment, since trees smaller than 12 inches were removed. The uniform stand conditions are also apparent by the distribution of trees in the dominant, co-dominant, and intermediate crown classes. If the stand had more large overstory trees, the percentage of trees in the dominant crown class would be higher, since these trees would not have been removed during thinning. Although trees were of similar size, the treatment created variable spacing between trees.

In many areas with high tree density and high canopy cover the ground is carpeted thickly with pine needles, with little grass cover (photo A). Typically in areas where there is an opening in the canopy, grass and herbaceous plants are more abundant (photo B). Sites where the forest structure is even more open usually have a higher percentage of understory cover (photo C), provided the site has not been over-grazed. Healthy remnant patches of grass and herbaceous plants are important because they provide a viable seed source to colonize areas that have little ground cover.

Slash was still present when photos were taken. Slash was lopped and scattered. Because slash levels were relatively low, a prescribed burn in the winter will be used to reduce the fuels. Regeneration that survives the prescribed burn will contribute to a multi-aged and multi-storied stand.

Hand crews harvested the trees and ground disturbance was not apparent. While trees were removed from the site for fuelwood using pick-up trucks, there was little evidence of tire tracks.

**Project:** **Santa Fe Watershed**

**Location:** New Mexico, Santa Fe National Forest, Española Ranger District

**Prescription:** The overarching goals of treatment are to reduce the risk of a severe crown fire and restore sustainable watershed conditions. To achieve these goals:

Initially cut all trees less than 9-10" diameter. Achieve a spacing of at least 20 feet between the crowns of individual trees or small groups of trees, leaving 50-80 large trees/acre. Remove trees >9-10" diameter if necessary to achieve spacing. Prune lower limbs of residual trees flush with the bole of the tree if the limb contains a mistletoe broom.

For trees over 8" diameter, lop the trees at the 6" diameter. Limb the logs and lay them along the contours for erosion control. Pile all slash less than 6" in diameter. Locate pile out from under tree crowns. Piles should contain fine fuels to allow ignition. Piles should have a conical shape, and should be no greater than 6' high or 8' in diameter. Avoid constructing numerous tiny piles. When conditions are suitable, burn piles. Follow with a broadcast burn.

**Project Size:** 7,270 acres

**Status:** Forest Service crews thinned 6 acres in the summer of 2002. The untreated portion is scheduled for treatment by a contractor and will be machine thinned.

**Implementation:** Hand thinning

## Photos: Santa Fe Watershed

**A.**
*A group of trees with interlocking crowns is apparent in the photo of the untreated area. Note the attempt to recreate this structure in the treated area.*


Untreated


Treated

**B.**
*Thinning reduced the high density of small diameter trees.*


Untreated

**C.**
*Tree boles were limbed and placed on the ground for erosion control.*


Treated

**Table: 7 Santa Fe Watershed**

| | Untreated | Treated |
|---|---|---|
| Trees | | |
| Species Composition: *Ponderosa Pine* | 100% | 100% |
| Live Trees per acre | 230 | 80 |
| Basal Area | 101 $ft^2$/acre | 88 $ft^2$/acre |
| Average Diameter of Adult Trees | 9.0 in | 14.5 in |
| Condition: *healthy* | 62% | 100% |
| *stressed* | 37% | 0 |
| *dying* | 1% | 0 |
| Canopy Characteristics | | |
| % Canopy Closure | 49% | 44% |
| Average Crown Base Height | 21-25 ft | >25 ft |
| Crown Base Height of the Lowest 20% | 11-15 ft | >25 ft |
| Crown Class: *dominant* | 10% | 20% |
| *co-dominant* | 24% | 62% |
| *intermediate* | 55% | 14% |
| *suppressed* | 11% | 4% |
| Regeneration | | |
| Saplings per acre | 413 | 0 |
| Seedlings per acre | 288 | 63 |
| Number of Plots | 4 | 2 |

**Observations: Santa Fe Watershed**

Because only a small area had been treated at the time of sampling, it was not possible to place an equal number of plots in the untreated and treated areas. In addition, it was difficult to find an untreated area that corresponded well, in terms of similar slope and aspect, to the treated area. Thus, the observations are limited to characteristics that were comparable in the treated and untreated areas.

The number of trees per acre is particularly high in the untreated area, reflecting that the untreated stand had dense areas of small trees.

The outcome of the treatment corresponded closely to the goals in the prescription. The average density in the treated area is 80 trees per acre, corresponding closely to the target density in the prescription (50-80 trees per acre). Small diameter trees were removed, as reflected in the relatively large average diameter in the treated site (14.5"). These large diameter trees were also healthy, as compared with the high level of stressed trees in the untreated site. Healthy overstory trees suggests that at least in some stands within this project, remnant historic forest structure has persisted.

Reducing ladder fuels was one objective of the thinning treatment. The average crown base height in the treated area is greater than 25 feet, meeting this objective. Another method used to reduce ladder fuels was to remove saplings. There are fewer saplings in treated areas than in untreated areas.

Numerous slash piles were created from thinning. Small slash piles are evident in the foreground of both treated photos. A high amount of slash was generated from the small treatment area, suggesting that slash reduction will be a major undertaking as the project progresses.

Harvest-created clumps were created at in the Santa Fe Watershed (photo A of the treated site). Clumps are characteristic of the historic structure of ponderosa pine forests and can serve as a model for future desired conditions in stands that are more uniformly spaced due to past management. Trees within a clump have interlocking crowns and are distinct from the surrounding canopy. Tree clumps were created within the treated area, although not specified in the prescription.

The treated site profiled in this report may not reflect the majority of the treated sites in the Santa Fe Watershed project. This treated site profiled here was thinned by a Santa Fe National Forest fire fighting crew. The majority of the project is being mechanically treated by a private contractor.

**Project:** **David Canyon**

**Location:** New Mexico, Cibola National Forest, Sandia Ranger District

**Project Size:** 275 acres. David Canyon is located in a transition ecotone between pinyon-juniper woodland and ponderosa pine.

**Prescription:** A heavy "thinning from below" (removing the smallest diameter trees) is prescribed across the project area. Reduce overall residual basal to 40-50 $ft^2$/acre or 73-92 trees per acre. Average spacing will be 22-24 feet. Achieve this spacing by designating for removal diseased, damaged or excess trees from all age classes (beginning at the 5" diameter class and moving upwards) of pinyon pine, small ponderosa pine, and juniper.

Retain all Gambel oak (>5" dbh) and mature yellow bark ponderosa pine. Retain all live trees with nesting cavities. Retain all dead, standing trees >12" dbh and >15' tall.

Untreated groups of vegetation may be retained at the direction of the wildlife biologist.

Prescribe burn or pile and burn to treat residual slash. Re-entry, using either mechanical or burning treatments, is recommended at 2-3 year intervals to control prolific oak sprouting.

**Status:** The treated area that was sampled is scheduled for prescribed fire. A portion of the treated area that was not sampled was prescribed burned in 2001 and 2002.

**Implementation:** Hand thinning by fuelwood harvesters.

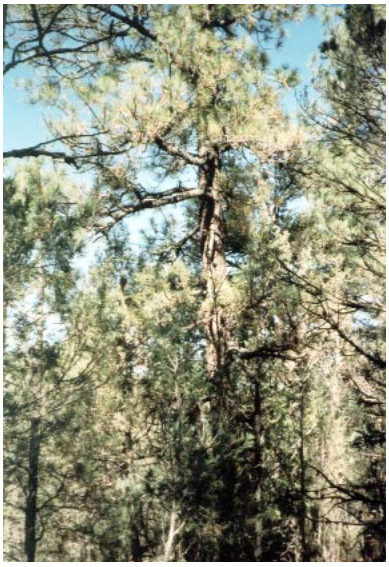
**Photos:**
**David Canyon**

**A.**
*Dense understory is present in the untreated site. The clearing of the understory reduced ladder fuels, which are still evident but not as significant , in the treated site.*


Untreated


Treated

**B.**
*The dense understory in the untreated site obscures the large tree present in the photo. Ladder fuels were removed from beneath trees in the treated site.*


Untreated


Treated

**C.**
*The thin from below prescription focused on leaving large diameter trees and removing ladder fuels beneath the tree crowns.*


Untreated


Treated

**Table: 8 David Canyon**

| | | Untreated | Treated |
|---|---|---|---|
| Trees | | | |
| Species Composition: | *Ponderosa Pine* | 82% | 81% |
| | *Pinyon* | 9% | 19% |
| | *Juniper* | 9% | 0 |
| Live Trees per acre | | 215 | 65 |
| Basal Area | | 102 $ft^2$/acre | 71 $ft^2$/acre |
| Average Diameter of Adult Trees | | 8.7 in | 13.5 in |
| Condition: | *healthy* | 73% | 88% |
| | *stressed* | 23% | 12% |
| | *dying* | 4% | 0 |
| Canopy Characteristics | | | |
| % Canopy Closure | | 49% | 26% |
| Average Crown Base Height | | 16-20 ft | 21-25 ft |
| Crown Base Height of the Lowest 20% | | 11-15 ft | 11-15 ft |
| Crown Class: | *dominant* | 26% | 50% |
| | *co-dominant* | 35% | 40% |
| | *intermediate* | 25% | 8% |
| | *suppressed* | 14% | 2% |
| Regeneration | | | |
| Saplings per acre | | 200 | 88 |
| Seedlings per acre | | 275 | 350 |
| Number of Plots | | 4 | 4 |

**Observations: David Canyon**

Fuel reduction treatments have occurred in David Canyon over the past few years. The remaining untreated area is not directly comparable to the treated area. For example, scattered, mature ponderosa pine occur more frequently in the treated area, while groups of immature "blackjack" ponderosa pine are more common in the untreated area. These conditions exaggerate the differences in density, basal area, average diameter, and crown class between the treated and untreated areas.

The average diameter in the untreated area is small and approximately a quarter of the trees are stressed. The high percent canopy closure suggests that crowns are competing, contributing to the stressed condition of the trees. The high percent canopy closure also suggests that crown fuels are continuous in some areas. The low crown base height and the high number of saplings illustrates the presence of ladder fuels. Because of these conditions, the area was selected for thinning.

The average diameter in the treated area is 13.5" and the majority of the trees are healthy. This project appeared to focus entirely on removing the smallest diameter trees, as stated in the prescription. The density of trees (65 trees per acre) is slightly below the target described in the prescription (73-92 trees per acre), although basal area (71 $ft^2$/acre) is above the target of 40-50 $ft^2$/acre. Canopy closure is 26%, suggesting that tree canopy cover is not continuous.

High numbers of seedlings and saplings remain in the treated area, contributing to both surface and ladder fuels. However, data was collected before the prescribed burn had been implemented and a fire will likely reduce the tree regeneration significantly. The high numbers of seedlings and saplings, along with a lot of Gambel oak, suggests the importance of implementing the prescribed burn as planned. Prescribed fire can reduce ladder fuels such as Gambel oak (photos A and photos B). Some land managers have found that cutting oaks results in increased re-sprouting, while thinning oak using prescribed fire results in fewer sprouts (pers. obs. Alex Allen).

The average crown base height in the treated stand was only slightly higher than the untreated stand. It is likely that prescribed fire will be used to help prune the lower branches of trees.

The unit sampled for this project was one of three David Canyon treatment units. The canyon is adjacent to a low density subdivision completely surrounded by the Cibola National Forest. This project has proceeded slowly but continually over the last four years. Forest Service staff on the Sandia Ranger District spent considerable time educating the public, particularly in the neighborhood surrounding the project. Consequently, community support for the project has been strong, even during prescribed burning.

**Project:** **Ruedas**

**Location:** New Mexico. Carson National Forest, Camino Real Ranger District

**Project Size:** The treated area is 110 acres in size. The untreated area was located beyond the periphery of the treated unit.

**Prescription:** Thin to 60-70 BA. Leave 110 to 100 trees per acre, depending on size of trees in area. Create 14 to 20 feet spacing between trees. Follow thinning with prescribed fire.

**Status:** Areas of the stand have been prescribed burned. Burning will continue throughout the remainder of the stand. In some areas, additional small diameter trees will be removed prior to burning.

**Implementation:** Public fuelwood removal. Used stewardship blocks to assist with fuelwood removal (Schumann and Derr 2001). Forest Service crews worked in some areas to remove small diameter trees.

## Photos: Ruedas

**A.**

*Tree density is lower in the treated area than in the untreated area. Small stumps present in the pre-treatment photo are from a thinning 10-15 years ago.*

Pre-Treatment

photo credit: H. Lopez

Post-Treatment

**B.**

*Percent canopy closure is lower in the treated area than in the untreated area. Tree crowns obscure the sky in the pre-treatment photo, but the sky is visible after the treatment because the crowns are no longer touching.*

Pre-Treatment

photo credit: H. Lopez

Post-Treatment

**C.**

*Conditions throughout the treated unit are not uniform. In the photo on the left, a clump of fairly dense trees is pictured. The photo on the right shows a more open area with overstory yellow-pines.*

Treated

Treated

**Table 9: Ruedas**

| | Untreated | Treated |
|---|---|---|
| Trees | | |
| Species Composition: *Ponderosa Pine* | 92% | 100% |
| *Pinyon* | 7% | 0 |
| *Juniper* | 1% | 0 |
| Live Trees per acre | 210 | 100 |
| Basal Area | 100 $ft^2$/acre | 58 $ft^2$/acre |
| Average Diameter of Adult Trees | 9 in | 10 in |
| Condition: *healthy* | 74% | 100% |
| *stressed* | 26% | 0 |
| *dying* | 0 | 0 |
| Canopy Characteristics | | |
| % Canopy Closure | 49% | 28% |
| Average Crown Base Height | 16-20 ft | 16-20 ft |
| Crown Base Height of the Lowest 20% | 6-10 ft | 6-10 ft |
| Crown Class: *dominant* | 24% | 33% |
| *co-dominant* | 53% | 50% |
| *intermediate* | 18% | 17% |
| *suppressed* | 5% | 0% |
| Regeneration | | |
| Saplings per acre | 38 | 0 |
| Seedlings per acre | 338 | 163 |
| Number of Plots | 4 | 4 |

**Observations: Ruedas**

The Ruedas thinning project has occurred over the past few years, covering a fairly large area. For this site we used photos of before and after treatment and data collected from untreated adjacent and treated sites. The untreated area represents a slightly different condition than what is found in the treated area. Ponderosa pine occurs more frequently in the overstory in the treated area, while pinyon and juniper trees are found more frequently in the untreated area. Therefore, it is instructive to look at conditions within each area, rather than comparing conditions between the treated and untreated areas.

Tree density is lower in the treated area than in the untreated area, reflecting a goal of the prescription. As a result of lower tree density, crowns are spaced farther apart, decreasing the ability of a crown fire to spread. The percent canopy closure is also lower in the treated area than in the untreated area, also decreasing the ability of a crown fire to spread.

The Ruedas site is a good example of a typical even-aged young ponderosa pine stand. The age and spacing of the trees are relatively uniform and there are few large diameter trees. The average size of trees prior to treatment was 8-10." Even though the stand was marked for a 'thin from below,' the average diameter after treatment is not very large (10" dbh). This relatively small average diameter reflects a lack of large diameter trees at the site.

This project successfully reduced fuels. The land managers were challenged, however, to create diversity in the arrangement of trees. The trees are fairly uniformly spaced (post-treatment photos A and B), similar to pre-treatment conditions in this even-aged stand. However, increasing structural diversity was not a goal stated in the prescription.

The entire treated area was in various stages of completion. Some areas had been burned already, while other areas still had high levels of slash and downed logs.

One undesired outcome of disturbing the ground through harvesting and burning is an increased presence of exotic plants (photo C, photo on the right). Many exotic plants thrive on disturbance, may displace native plants and may not benefit native insects and herbivores. Thistle and mullein plants in the foreground of the photo C are common exotics.

**Project:** **Dollar**

**Location:** New Mexico, Santa Fe National Forest, Jemez Ranger District

**Prescription:** Space leave trees 10-20 feet apart. Do not cut trees greater than 12 inches unless infested with mistletoe. Hand pile slash and burn piles.

**Project Size:** Approximately 20 acres.

**Status:** Project completed.

**Implementation:** A commercial thinning contract accomplished a first entry. The contractor defaulted. Forest Service crews made a second entry, leaving the wood on the ground to be removed through fuelwood permits.

## Photos: Dollar

**A.**
*Ladder fuels, saplings and low branches, are present in the background of the untreated area. The treated area has large diameter trees with high crown base heights.*


Untreated


Treated

**B.**
*Clumps of small diameter trees are visible in this photo of the untreated area. Small diameter trees were removed in the treated area.*


Untreated


Treated

**C.**
*The treated photo shows that there was an attempt to leave clumps of trees. The crowns within the group of trees are separated from the crowns of adjacent trees, apparent because of the sky that is visible in the upper left-hand corner of the photo.*


Untreated


Treated

**Table 10: Dollar**

| | Untreated | Treated |
|---|---|---|
| Trees | | |
| Species Composition: *Ponderosa Pine* | 100% | 100% |
| Live Trees per acre | 207 | 113 |
| Basal Area | 161 $ft^2$/acre | 115 $ft^2$/acre |
| Average Diameter of Adult Trees | 11.1 in | 13.2 in |
| Condition: *healthy* | 57% | 100% |
| *stressed* | 43% | 0 |
| *dying* | 0 | 0 |
| Canopy Characteristics | | |
| % Canopy Closure | 39% | 36% |
| Average Crown Base Height | 21-25 ft | >25 ft |
| Crown Base Height of the Lowest 20% | 21-25 ft | >25 ft |
| Crown Class: *dominant* | 22% | 15% |
| *co-dominant* | 32% | 68% |
| *intermediate* | 32% | 17% |
| *suppressed* | 14% | 0% |
| Regeneration | | |
| Saplings per acre | 17 | 0 |
| Seedlings per acre | 67 | 0 |
| Number of Plots | 3 | 3 |

**Observations:** **Dollar**

The treatment followed the prescription, focusing on removing small diameter trees. The average diameter was 13.2" in the treated site, compared with 11.1" in the untreated site. The trees in the treated area were, on average, more healthy than trees in the untreated area. In the treated area, the presence of large overstory trees helped create vertical diversity with varying canopy layers. Having fewer but larger trees also created a more open forest structure.

Crowns of trees in the treated site were separated to decrease the likelihood of a crown fire spreading, an observation made while walking through the site. The values for percent canopy closure, similar in both the untreated and treated site, do not reflect this observation.

As illustrated in photo pair A, crown base heights were higher in the treated area than in the untreated site. This will facilitate re-introduction of surface fire.

Slash was removed from the treated site through pile burning. Note the small slash piles in photo A of the treated site. Small piles make burning more manageable.

Ground disturbance from harvesting was not visible at this site. The ground was carpeted with a thick layer of pine needles and occasional patches of grass. Opening the canopy and carrying out prescribed burning should increase the residual ground cover.

**Project:** **Colt Commercial Thinning**

**Location:** Colorado, San Juan National Forest, Dolores R.D.

**Prescription:**

1. Create a residual basal area of 65-75 $ft^2$/acre with a somewhat clumpy distribution.
2. Increase average stand diameter, accentuating a partially uneven-aged character.
3. Increase crown base height by 20% or more.
4. Reduce cover of woody plants (e.g. Gambel oak) and detritus (litter and woody debris). Reduce the canopy cover percent of Gambel oak by 10 to 30%. Reduce the depth of litter to less than 1″. Ensure that the quantity of 1 to 10 hour fuels is less than pre-harvest conditions.
5. Reduce down woody fuels. The tons/acre of 100-hour fuels are below pre-harvest conditions.
6. Increase habitat diversity. Leave clumps of trees up to 1/4 acres in size. Create openings up to 1/4 acre in size.
7. Follow thinning with a prescribed burn.
8. Save all snags.
9. Leave all trees with old growth attributes (yellow platey bark and flat topped crowns).

Note: The Dolores RD used it's "commercial thinning" prescription for this site because there were not many large trees >14" on the site (see Note on page 21).

**Project Size:** The treated unit is approximately 30 acres in size.

**Status:** Thinning, wood removal, and slash disposal is complete. Prescribed burning is planned.

**Implementation:** Commercial Timber Sale.

## Photos: Colt Commercial Thinning

**A.**
*Openings, such as the area around the tree in the treated area, contributed to the low average percent canopy cover.*

Untreated

Treated

**B.**
*Average tree density was much higher in the untreated area than the treated area. Small diameter trees were removed in the treated site, creating wider spaces between the largest trees.*

Untreated

Treated

**Table 11: Colt Commercial Thinning**

| | Untreated | Treated |
|---|---|---|
| Trees | | |
| Species Composition: *Ponderosa Pine* | 100% | 100% |
| Live Trees per acre | 203 | 43 |
| Basal Area | 213 $ft^2$/acre | 91 $ft^2$/acre |
| Average Diameter of Adult Trees | 12.9 in | 17.4 in |
| Condition: *healthy* | 50% | 100% |
| *stressed* | 47% | 0 |
| *dying* | 3% | 0 |
| Canopy Characteristics | | |
| % Canopy Closure | 33% | 9% |
| Average Crown Base Height | 21-25 ft | >25 ft |
| Crown Base Height of the Lowest 20% | 11-15 ft | 21-25 ft |
| Crown Class: *dominant* | 24% | 64% |
| *co-dominant* | 20% | 0 |
| *intermediate* | 12% | 22% |
| *suppressed* | 44% | 0 |
| Regeneration | | |
| Saplings per acre | 17 | 0 |
| Seedlings per acre | 17 | 0 |
| Number of Plots | 3 | 3 |

**Observations: Colt Commercial Thinning**

The treatment was successful in reaching a number of the goals stated in the prescription. In the treated area, both the average tree density and basal area were lower than in the untreated area. The average basal area in the treated area was higher than the target value, which suggests that not as much basal area was removed as prescribed. Because small trees were removed in the treated site, the average diameter in the treated area was 17.4", compared with an average diameter of 12.9" in the untreated area. Larger, healthier trees were chosen as leave trees; this is reflected in the values for crown and condition classes.

Reflecting a goal of the prescription, crown base height was higher in the treated area. While low crowns are often seen as a mechanism to carry a surface fire into a tree crown (as seen in photo C of the untreated area), saplings and shrubs also provide ladder fuels. Gambel oak is present in the untreated area (photo A), while thinned Gambel oak stems are present in the foreground of the treated area in photo A. These stems may sprout back or need periodic prescribed fire to control so that they do not become ladder fuels in the future.

Down woody fuels are seen in the treated sites shown in photos A and B. When prescribed burning occurs, these fuels will be reduced. This prescription is unique in this study in that it specifies that the amount of 100-hour fuels be lower than pre-harvest levels. Consequently, slash levels after treatment are low, facilitating the use of prescribed fire. Ground disturbance from logging was minimal, in contrast with other sites that were commercially harvested.

The resulting arrangement of trees tended to be clumpy, with openings and dense patches with interlocking crowns. A group of trees with interlocking crowns is seen in the background of the treated photo A, while there is an opening in the foreground of the photo. Harvest-created openings can help increase the diversity of forest structure within a stand. The space created by an opening contrasts with residual clumps and groups of trees. The remarkably low percent canopy cover (9%) reflects that canopy transects coincided with openings. This low value does not appear to accurately reflect the average canopy cover at the site.

Regeneration is low in the untreated site and currently absent in the treated site. Regeneration will probably increase over time with the opening of the canopy and the prescribed fire.

**Project:** **Spring Valley**

**Location:** Arizona. Kaibab National Forest, Williams Ranger District

**Prescription:** Do not cut Yellow pines and generally do not cut trees greater than 12″. Create a residual basal area of 110-130 $ft^2$/acre. Create openings from $^1/_4$ to $^1/_2$ acre in size. Pile slash.

Pile slash and burn piles. Follow with broadcast burn.

**Project Size:** Untreated unit is 48 acres. Treated unit is 23 acres.

**Status:** Slash piles still need to be burned.

**Implementation:** Timber Sale. Machine skidding.

## Photos: Spring Valley

**A.**
*The treated stand was thinned uniformly in many areas.*


Untreated


Treated

**B.**
*Tree density was lower by more than half in the treated site, compared with the untreated site.*


Untreated


Treated

**C.**
*The prescription called for creating openings in the treated site that mimic natural openings in the forest, such as the opening present in the untreated site.*


Untreated


Treated

**Table 12: Spring Valley**

| | Untreated | Treated |
|---|---|---|
| Trees | | |
| Species Composition: *Ponderosa Pine* | 100% | 100% |
| Live Trees per acre | 202 | 88 |
| Basal Area | 187 $ft^2$/acre | 93 $ft^2$/acre |
| Average Diameter of Adult Trees | 13.2 in | 14.1 in |
| Condition: *healthy* | 92% | 98% |
| *stressed* | 8% | 2% |
| *dying* | 0 | 0 |
| Canopy Characteristics | | |
| % Canopy Closure | 54% | 34% |
| Average Crown Base Height | 16-20 ft | >25 ft |
| Crown Base Height of the Lowest 20% | 11-15 ft | >25 ft |
| Crown Class: *dominant* | 20% | 35% |
| *co-dominant* | 39% | 44% |
| *intermediate* | 32% | 18% |
| *suppressed* | 9% | 3% |
| Regeneration | | |
| Saplings per acre | 17 | 0 |
| Seedlings per acre | 0 | 0 |
| Number of Plots | 6 | 6 |

**Observations: Spring Valley**

Removing small diameter trees was the focus of this timber sale, as reflected in the average diameter which was 13.2" in the untreated stand and 14.1" in the treated area. This increase is fairly small, corresponding to the observation that there were not very many small trees to be removed in the treated site. Small diameter trees are far more numerous in the untreated photos than in the treated photos. Subsequently, the treated stand has fewer stressed trees and trees of intermediate crown class.

The basal area in the treated area was 93 $ft^2$/acre, which is less than the prescription target of 110-130 $ft^2$/acre. The stand was thinned quite heavily.

The treated stand was in a goshawk habitat, and therefore the prescription called for thinning less heavily than a typical wildland urban interface treatment abutting residential areas. A typical prescription for a wildland urban interface treatment on the Williams R.D. would reduce basal area to 70 $ft^2$/acre, whereas this prescription called for 110-130 $ft^2$/acre.

The fuel profile was altered by the treatment. Crown base heights were high (>25 ft) in the treated area. The presence of slash can present significant surface fuels, but in this case slash was removed from the stand and piled at landings by the road. Ladder fuels, in the form of shrubs, seedlings, and saplings were absent in the treated site.

There appeared to be few large diameter yellow-pines in the treated site. The presence of these trees would have been reflected in a larger average diameter and a larger percent of dominant trees. While average diameter in the untreated site was fairly large (13.2"), the untreated stand was fairly uniform in tree size and spacing.

This prescription does not include the goal of creating a more diverse forest structure. Therefore, it is not surprising that the site, after treatment, was fairly uniform. At this site, openings were created. Harvest-created openings can help increase the diversity of forest structure within a stand. Some land managers attempt to create an overall density of trees that is variably distributed. For example, the absence of trees in openings balances the higher density of trees found in residual clumps and groups. At this site, residual clumps and groups were not retained.

**Project:** **Bruno Tank**

**Location:** Arizona, Apache-Sitgreaves National Forest, Black Mesa Ranger District

**Prescription:** Leave all trees >7" diameter. Average spacing between trees of 20 feet. Slash (defined as wood <4" in diameter) to be piled.

**Project Size:** Untreated units 3 & 4 together cover 163 acres. The treated unit is approximately 90 acres.

**Status:** The untreated unit will be treated in 2003. The prescription for the untreated site changed after the Rodeo-Chediski fire, which burned directly adjacent to site (summer 2002).

**Implementation:** Hand thinning. Tree stems chipped. Slash hand-piled and burned.

**Photos:**
**Bruno Tank**

**A.**
*Dense regeneration presented significant ladder fuels in the untreated stands, but was reduced in the treated stand.*


Untreated


Treated

**B.**
*Removal of small diameter trees reduced competition for resources, with the goal of increasing individual tree health. In the photo of the untreated stand, the crown of the overstory tree in the background is dying back (on the right hand side of the photo). The crowns of trees in the treated photo are healthy.*


Untreated


Treated

**C.**
*In the left photo, the regeneration is out-competing the overstory trees, which are visibly dying from mistletoe. In right photo, the presence of large overstory pines seems to inhibit regeneration directly beneath the tree crowns (or above the root balls).*


Untreated


Untreated

**Table 13: Bruno Tank**

| | Untreated | Treated |
|---|---|---|
| Trees | | |
| Species Composition: *Ponderosa Pine* | 100% | 100% |
| Live Trees per acre | 84 | 110 |
| Basal Area | 131 $ft^2$/acre | 78 $ft^2$/acre |
| Average Diameter of Adult Trees | 16.8 in | 11.7 in |
| Condition: *healthy* | 97% | 92% |
| *stressed* | 3% | 8% |
| *dying* | 0 | 0 |
| Canopy Characteristics | | |
| % Canopy Closure | 58% | 22% |
| Average Crown Base Height | 21-25 ft | 21-25 ft |
| Crown Base Height of the Lowest 20% | 11-15 ft | 11-15 ft |
| Crown Class: *dominant* | 32% | 20% |
| *co-dominant* | 23% | 49% |
| *intermediate* | 37% | 31% |
| *suppressed* | 8% | 0 |
| Regeneration | | |
| Saplings per acre | 1112 | 25 |
| Seedlings per acre | 3090 | 250 |
| Number of Plots | 4 | 2 |

**Observations: Bruno Tank**

The treated site was sampled using only two plots because of the expectation to revisit the site and collect post-treatment data. Scheduled treatment of the untreated site was altered because of the 2002 Rodeo-Chediski wildfire. The treated site was adjacent to the untreated site, but differed in terms of forest structure, as described below.

The untreated site had few adult trees (trees greater than 5" dbh), but these trees were large (16.8" dbh). Looking at the density of adult trees alone (84 trees per acre), one might conclude that the site does not need treatment. However, the pine regeneration presented significant ladder fuels (photo pairs A, B, and C). Saplings and seedlings together averaged 4,202 stems per acre, illustrating that the majority of trees in the untreated site were less than 5" diameter. Competition for resources by the regeneration had a pronounced effect on the overstory pines. Many overstory trees were killed by mistletoe, presumably because the competition for water diminished their resilience. The data for this site illustrates the importance of looking at numerous variables when evaluating forest structure.

The treated site had far fewer large diameter yellow-pines than the untreated site. The treated side had more adult trees (110 trees per acre), but they were on average smaller than in the untreated unit (11.7" dbh). Thinning separated the tree crowns (photo B). The trees remaining after thinning were healthy.

The prescription focused on reducing ladder fuels and competition, which was accomplished in the treated site. The average crown base height, an indicator of ladder fuels, appears to be the same in the untreated and treated sites. Had the crown base height of saplings been considered in the untreated sites, the value would have been much lower (since the presence of so many saplings created significant ladder fuels). However, only the crown base height of adult trees was measured.

Dense small-diameter thickets of stunted ponderosa pine trees (Photos A), commonly referred to commonly as 'doghair thickets,' pose a fire risk. The trees are weak due to competition for light and water, and understory vegetation is absent. In some areas, stunted, weak trees have begun to fall over, thinning themselves. Historically, fire would have helped thin these dense stands long before they grew as tall as the trees in these photos.

## Chapter 4: Conclusions

All of the treatments achieved the overarching objective of their prescription, to reduce fuels. Following are some conclusions about the general effects of fuel reduction prescriptions:

- All treatments changed the existing canopy structure by breaking up continuous canopy fuels and removing ladder fuels that can carry a surface fire into the crowns. In some cases, following the thinning with prescribed fire will be necessary to further reduce ladder fuels.

- Fuel reduction in the majority of sites focused entirely on removing small diameter trees. All of the prescriptions for sites included in this project include guidelines for what size trees to remove or retain. The most commonly used cut-off for determining a "large tree" was 12 inches in diameter. Most prescriptions suggested leaving trees larger than 12 inches in diameter, unless mistletoe or bark beetles are present.

- Some sites with a greater proportion of large trees used timber sales to remove merchantable timber, in addition to small diameter trees. Projects with a commercial component used mechanical equipment that in some cases caused ground disturbance.

- The risk of increasing the surface fuel load after harvesting was addressed in all projects. Slash was treated at all sites, with a variety of methods ranging from lop and scatter, small piles, large piles, pile burning, broadcast burning, and complete removal.

- Most fuel reduction treatments improved average stand vigor by removing stressed trees with small crowns.

- While a number of project prescriptions include the goal of prescribed burning, most of these projects have not been burned yet. Half of the projects demonstrated a commitment to conducting prescribed fires (i.e. fire had occurred at the stand surveyed or within other stands of the project). Other projects reduced the fuel load sufficiently to allow prescribed fire to be used, once resources are available and conditions are appropriate.

- Sites that were treated more than a year ago had increased vegetative ground cover. Understory plant cover serves several functions; it provides food and cover for wildlife, protects the soil surface from erosion, provides fuel to carry surface fires, protects the soil, and inhibits tree regeneration (Savage 2002). Restoring these functions is an important component of fuel reduction projects.

The stand structure varied among sites receiving restoration and fuel reduction treatments. Untreated sites represented a range of conditions, some with a high density of small diameter trees. An assessment of the need for treatment was probably based on the presence of surface, ladder, and canopy fuels and the desire to alter these conditions through treatment. Following are some conclusions about the relationship between existing stand conditions and treatment outcomes.

- A uniform stand prior to treatment will probably be uniform after treatment. It is challenging to create more diverse forest structure from a relatively young forest (80-100 years) with similarly sized and spaced trees.

- If a stand has diverse forest structure prior to treatment, such as clumps, groups, openings and large diameter trees, prescriptions can build on this structural diversity. Thinning can occur around clumps and groups, and can maintain canopy openings.

- When any single attribute, such as tree density or canopy cover, is the focus of a treatment, results tend to be more uniform. When a number of forest characteristics are considered together, such as tree density and the spatial arrangement of trees, results tend to be more diverse. For example, a prescription may specify that average tree density should be 100 trees per acre. There are different ways of achieving this goal. One is to create a stand with a density of 100 trees per acre throughout. Another approach is to create areas with a densities of 50, 100 and 150 trees per acre.

- Treatments were more likely to create openings than leave dense groups. This may reflect the experience of the foresters or harvesters involved in projects, in that cutting all the trees in a given area is easier than marking a group of trees of variable size to leave uncut.

- Most sites had very low levels of seedlings and saplings, given the closed canopy and thick litter layer. Three sites included the goal of recruiting regeneration, because the establishment of young pines contributes to developing the uneven-aged character of future stands.

The twenty-five prescriptions for fuel reduction projects sampled in this study varied considerably. Following are some conclusions about the prescriptions themselves:

- Some prescriptions include a high level of detail, articulating goals and objectives for the treatment. A more highly detailed prescription has a higher likelihood of achieving desired results. Prescriptions are typically written by a silviculturist, handed to a marker, and carried out by a thinning crew. If the goals and objectives are clearly stated in the prescription, all parties involved have a common understanding of the desired outcome of the treatment and the treatment will more likely achieve these goals. Examples of detailed prescriptions are:

  **To create crown spacing**, some prescriptions call for farther spacing between clumps (30-40 feet) than for individual trees (10-25 feet). Another prescription specified irregular spacing of 10-20 feet.

  **To create clumps**, one prescription specified leaving 2-5 trees that are distinct from the canopy of surrounding trees, with a basal area within the clump of 60 to 110 $ft^2$/acre. A prescription may also specify how many clumps should occur within a given stand of specific acreage.

  **To create groups**, a prescription may suggest leaving groups of trees from 1/2 to 1 acres in size. One prescription stated that minimum basal area within groups should be 120 $ft^2$/acre. A prescription may specify how much of an area designated to the thinning could be left with a higher density of trees. This 25% could be distributed throughout the stand as groups. A minimum number of groups, 20 for example, could be set. The groups could be variable in size, as long as the total area of all 20 groups was 25% of the entire treatment unit. Light thinning may occur within groups, as long as the minimum basal area is met. Describing how to create groups in a treatment unit is a way to clearly set targets for re-establishing horizontal spatial diversity.

  **To create openings**, prescriptions specify removing groups of trees from 1/2 to 1 acres in size. Harvest-created openings may build off existing openings. Openings may be created to enhance group or clump distribution. A prescription may specify that 10% of an area, for example, be managed for grassy openings. A given number of openings, 20 for example, could be specified.

- Some prescriptions list broad goals and do not provide much detail. Typically, brief prescriptions result in more uniform forest structure.

- No prescriptions listed target values for canopy cover. Canopy fuels are important in sustaining crown fire spread. Managers recognize this by recommending a desired distance between tree crowns, thereby reducing canopy cover. In addition, land managers probably assume that reducing tree density will translate into reduced canopy cover.

## Appendix: Definitions of Variables Measured

This section defines the variables measured at each site. Following the definition, is the rationale for measuring the variable, as it relates to the objective of fuel reduction. In some cases, the analysis of the data is explained.

*Average Diameter at breast height:*

Definition: The width of a tree is measured at 4.5 feet above the ground. The diameter of all live trees is averaged.

Rationale: Larger diameter ponderosa pine trees are more fire resistant. Fuel reduction projects to reduce fire hazard should increase the average diameter at a site. This is accomplished by removing the smallest diameter trees first, commonly referred to as 'thinning from below'.

*Basal Area:*

Definition: A measure of the area taken up by the trunks of trees at a site, most commonly expressed as $ft^2$/acre.

Rationale: Basal area is a commonly used characteristic by foresters to describe sites. Basal area has no direct biological significance to current stand structure, but traditionally has been used as a crude integrated expression of number of trees and their sizes. Basal area, expressed alone as a value, does not give any information about the density or average size of trees.

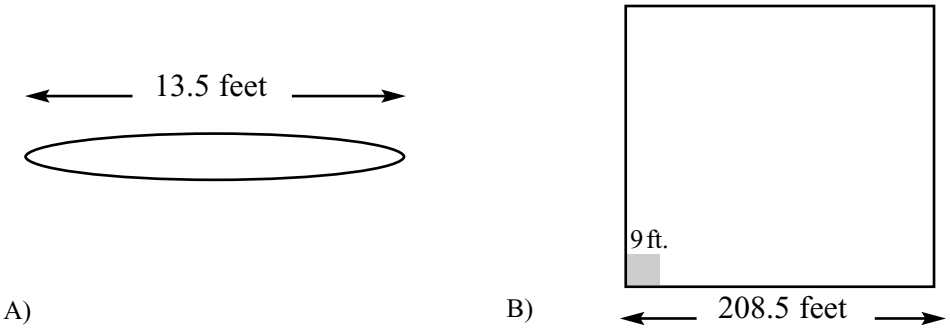



**Figure 1:** A) The basal area of a 1 tree with a diameter of 13.5 inches equals 1 $ft^2$/acre. B) A basal area of 81 $ft^2$/acre is depicted, as if all the trees were rearranged to show that basal area can be thought of as the space occupied by trees.

*Canopy Cover:* Definition: Percent of the sky that is covered by needles, leaves, branches, and twigs in the stand.

Rationale: A high percent canopy would suggest that there is a contiguous canopy cover, enabling an active crown fire. Fuel reduction projects to reduce fire hazard should reduce the canopy cover to reduce crown fire potential. Percent canopy cover also effects the ground cover, by determining how much light the forest floor receives.

**Figure 2:**
This box demonstrates what 50% canopy within a given area would look like. The value is a percent, therefore unit-less.

*Crown Base Height:* Definition: The vertical distance from the ground to the bottom of the live crown of an individual tree. A tree crown is the portion of the tree that includes live branches and needles.

Rationale: Separation between base of crown and surface fuels may prevent fire from burning into the crown. Fuel reduction projects should raise the average crown base height.

By presenting the average crown base height, information is lost about the variation in crown base height. Of specific interest is what portion of trees within a plot have a low crown base height. Forest managers are interested in the lowest crown base heights in a stand, because these trees facilitate the spread of a surface fire into the canopy. To address this question, the data is ranked by quintiles, 20% groups. In this way, the height of crowns in the lowest 20% can be compared to the average (Fule et al. 2001). It is possible that this susceptible quintile is a more important variable for evaluating the potential for crown fire than crown base height (Fule et al. 2001).

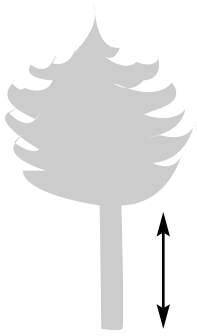


**Figure 3:** Crown base height is the distance from the ground to the bottom of the live crown.

*Crown Class:* Definition: A qualitative categorization to describe the position and size of a tree crown within the main canopy layer. Four crown classes are: dominant, co-dominant, intermediate, suppressed.

Rationale: Intermediate and suppressed trees may provide ladder fuels and are less healthy than dominant and co-dominant trees. Fuel reduction projects to reduce fire hazard should focus on removing intermediate and suppressed trees.

Data: Crown class is reported as the percent of each trees in each category (dominant, co-dominant, intermediate, suppressed). The number of trees in each of the four categories is divided by the total number of trees.

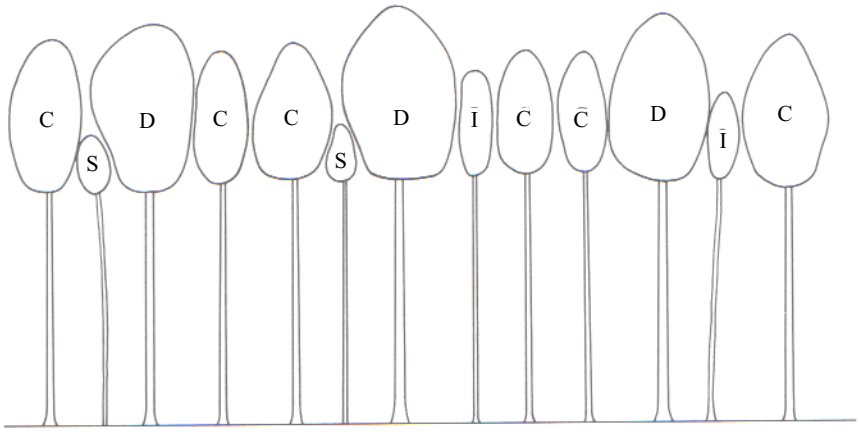



**Figure 4:** The relative positions of trees in different crown classes in a single-species stand with trees of all the same age. The letters D, C, I, and S denote dominant, codominant, intermediate, and suppressed crown classes, respectively. From "The Practice of Silviculture," Smith, 1992.

*Species Composition:* Definition: The percentage of all trees that are of a certain species.

Rationale: Recording tree species help describe the fuel complex. For example, the presence of Gambel oak and white fir suggests that ladder fuels exist. Species also describe site. Pinyon and juniper are present at dry sites, while Douglas fir is present on a site with more moisture.

*Surface Fuels:* Definition: Needles, leaves, grass, forbs, dead and down branches and boles, stumps, shrubs and short trees. Litter, vegetative ground cover, and woody debris and understory fuels were characterized at each site.

Rationale: Surface fuels facilitate fire spread, but in high amounts will increase the fire intensity. The absence of surface fuels suggests it will be difficult to conduct a prescribed fire. Dense forest canopy cover usually excludes healthy ground cover because the canopy limits light. In some cases, the litter layer is too thick and effectively excludes growth and germination of grasses and forbs (any leafy plant that is not a grass or woody like a shrub).

*Tree Condition:* Rationale: Fuel reduction projects to reduce fire hazard should focus on removing stressed and dying trees, particularly in the smaller diameter classes. Data may also show that some of the dominant trees are stressed due to competition.

*Trees per acre:* Definition: The number of trees per acre, also referred to as tree density.

Rationale: The number of trees describes an important component of the fuel complex.

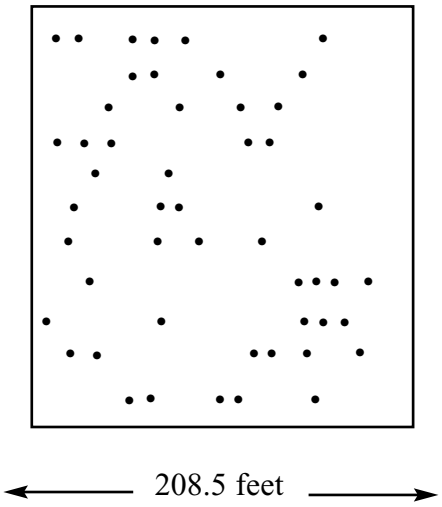



**Figure 5:** Dots in the box above represent 50 trees per acre. The box represents a square acre (1 acre = 43,453 $ft^2$). Note that density implies the number of trees per acre and not how they're arranged. This example portrays an acre of trees arranged in dense patches and with openings.

**Literature Cited**


Covington, W.W.; Moore, M.M. 1994. Southwestern ponderosa forest structure: changes since Euro-American settlement. *Journal of Forestry*. 92:39-47.

Covington,W.W.; Fule, P.Z.; Moore, M.M.; Hart, S.C.; Kolb, T.E.; Mast, J.N.; Sackett, S.S.; Wagner, M.R. 1997. Restoring ecosystem health in ponderosa pine forests of the Southwest. *Journal of Forestry*. 95(4): 23-29.

Cram, D.S.; Baker, T.T. 2003. *Inventory and classification of wildland fire effects in silviculturally treated vs. untreated forest stands of New Mexico and Arizona*. Annual Report. Cooperative Extension Service, College of Agriculture and Home Economics, New Mexico State University. Las Cruces, NM.

Fule, P.Z.; Waltz, A.E.M.; Covington, W.W.; Heinlein, T.A. 2001. Measuring forest restoration effectiveness in reducing hazardous fuels. *Journal of Forestry* 99 (1): 24-29.

Graves. D.A. and L.F. Neuenschwander 1999. The effects of thinning and similar stand treatments on fire behavior in Western forests. Gen.Tech. Rep. PNW-GTR-463. Portland, OR. USDA, Forest Service. Pacific Northwest Research Station. 27 p.

Issac, S.; and Michael, W.B. 1981. Handbook of research and evaluation. EdITS Publishers. San Diego, CA.

Lynch, D.L.; Romme, W.H.; Floyd, M.L. 2000. Forest restoration in southwestern ponderosa pine. *Journal of Forestry*: Vol. 98 (8).

Martinson, E.J.; Omi, P.N. 2002. *Effects of fuels treatment on wildfire severity*. Final report submitted to the Joint Fire Science Program Governing Board. March 25, 2002. Western Forest Fire Research Center, Colorado State University. Fort Collins, CO.

Pollet, J.; Omi, P.N . 2002. Effect of thinning and prescribed burning on crown fire severity in ponderosa pine forests. *International Journal of Wildland Fire* 11: 1-10.

Reinhardt, E.D. and K.C. Ryan. 1998. Analyzing effects of management actions including salvage, fuel treatment, and prescribed fire on fuel dynamics and fire potential. Pages 206-209 In Pruden, T.L. and L.A. Brennan. Fire in ecosystem management: shifting the paradigm from suppression to prescription. Tall Timbers Fire Ecology Conference Proceedings, No. 20. Tall Timbers Research Station, Tallahassee, FL.

Savage, M. 2002. *Community monitoring for restoration projects in southwestern ponderosa pine forests*. Forest Trust: Southwest Community Forestry Research Center Working Paper 5.

Schumann, M.S.; Derr, T.D. 2001. *Stewardship blocks: innovative tool brings fire plan benefits into community*. Fire Chronicle: Stories of the National Plan. Number 3. Forest Trust. http://www.theforesttrust.org/forest_protection.html.

Smith, D.M.; Larson, B.C.; Kelty, M.J.; Ashton, P.M.S. 1997. *The Practice of silviculture: applied forest ecology*. John Wiley & Sons, Inc. New York.

Scott, J.H. 1998. Fuel reduction in residential and scenic forests: a comparison of three treatments in a western Montana ponderosa pine stand. Res. Pap. RMRS-RP-5. USDA FS Rocky Mountain Research Station. 19 p.

Scott, J.H.; Reinhardt, E.D. 2001. *Assessing crown fire potential by linking models of surface and crown fire behavior*. Res. Pap. RMRS-RP-29. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station. 59p.

Stephens, S.C. 1998. Evaluation of the effects of silvicultural and fuels treatments on potential fire behavior in Sierra Nevada mixed-conifer forests. Forest Ecology and Management 105 (1): 21-35.

van Wagtendonk, J.W. 1996. Use of a deterministic fire growth model to test fuel treatments. In Status of the Sierra Nevada: Sierra Nevada Ecosystem Project Final Report to Congress Volume II. Wildland Resources Center Report No. 37. Center for Water and Wildland Resources. University of California, Davis. Page 1155-1165.