Mt. Trumbull Experimental Blocks: One year following treatment

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Introduction

The experimental block design at Mt. Trumbull was established to examine the effects of restoration treatments in a replicated design, allowing for strong inferences about treatment effects. Replicated large-scale experiments like this are rare and allow for unique research opportunities at the Mt. Trumbull restoration site. Initial findings from these units will be used to modify existing restoration treatments ongoing at the Mt. Trumbull research site, as well as contribute to restoration designs in ponderosa pine forests.

This design consisted of five blocks each containing two treatments: 1. control and 2. restoration thinning and burning. This paired design accounts for confounding variables, such as weather, site differences and grazing schedules, so that observed differences between the treatments are primarily due to a treatment effect. Four of the 5 blocks were treated between summer 1999 and spring 2000. The fifth block is currently being treated and is not included in this report.

This report is divided into four chapters, each addressing a different component of the ecological research in the experimental blocks. Chapter 1, Ponderosa Pine Structural Changes Through Time, assesses the historical, current-day and restored ponderosa pine structure. Specific questions that are examined in this chapter include: How does the overstory change with restoration treatment? Does restored overstory density and composition resemble historically reconstructed 1870 overstory density? How do canopy cover, diameter distributions and age distributions change with restoration treatments?

The second chapter examines effects of restoration treatment on potential fire behavior and crowning probabilities. Specific questions addressed here include: How does fire behavior change with restoration treatment? Does the restoration treatment decrease the risk of crown fire or torching? Can models assess the efficacy of thinning treatments as a fire prevention method?

Chapter 3, Understory Response to Restoration Treatments, compares the differences between control and treated forests in understory species richness, abundance and composition. Presettlement reference conditions are limited for understory conditions. In addition, little is known about understory reestablishment following 100 years of fire suppression and ecosystem degradation. Specific questions addressed include: How does the herbaceous community composition and abundance respond to restoration treatment? What is the range of variation in the herbaceous community across the Mt. Trumbull landscape?

Finally in chapter four, Wildfire and Restoration Treatment Results, we examine the results from an unplanned experiment; a wildfire. The effects of wildfire are compared to restoration treatment and a control (untreated) stand. The wildfire occurring in the Block 3 control resulted in the loss of pre-treatment control data for this block. A new control was established for this block in 2000, allowing for

within-year comparisons with treated forests. The wildfire, however, did provide a unique opportunity to examine pre-treatment and post-treatment community responses to wildfire, paired with community responses to restoration treatment.

Other questions currently being studied but not specifically addressed in this report include What effect does the edge created by restoration treatment have on abiotic variables, butterflies and bird communities? How does the small mammal community respond to restoration? How does the butterfly community respond to restoration treatments?

Methods

General methods discussed here will not be repeated in subsequent chapters.

Study Site Selection

Five experimental blocks were placed in the Mt. Trumbull Resource Conservation Area (RCA). The sites were chosen to block for landscape heterogeneity and were located in areas representing the different vegetation, topography and land-use history. The five experimental blocks vary in soil type, forest density, forest composition and herbaceous cover. Listed below is a brief description of each block:

Block 1: Located on shallow lava/cinder soils, this block has low tree density, consisting almost entirely of ponderosa pine, with many living presettlement trees. There is a large shrub component here, primarily serviceberry and wax currant.

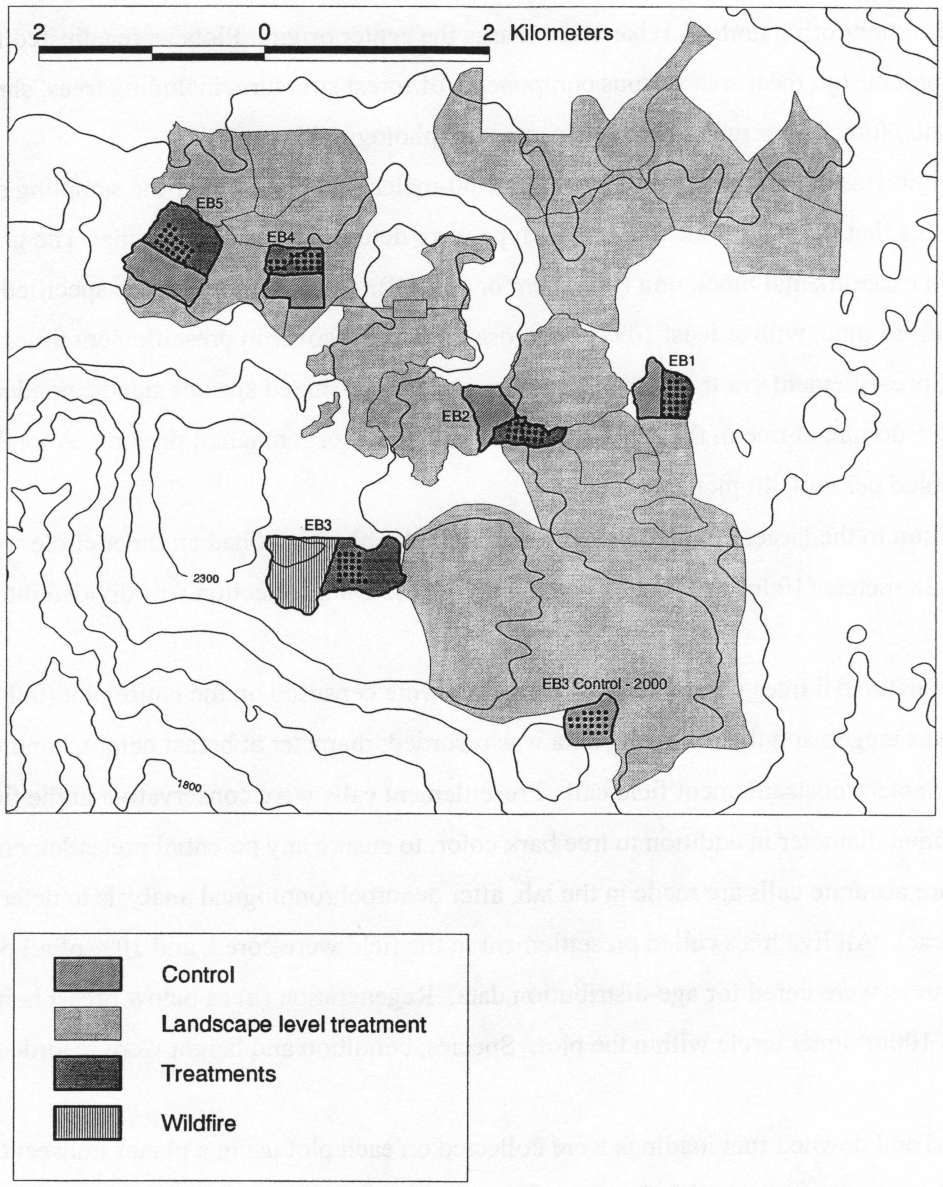
Block 2: This block has a strong Gambel oak component with an abundant herbaceous understory, including sagebrush openings, on basalt soils. This block is similar to a majority of the Mt. Trumbull treatments in the eastern portion of the RCA.

Block 3: At the highest elevation, block 3 is dominated by large, presettlement ponderosa pine, but also has Gambel oak and New Mexican locust throughout the unit. This unit is one of the largest (~100 acres) and is predominately on cinder soils.

Block 4: Block 4 represents the densest stands of ponderosa pine forest at Mt. Trumbull. It consists of dense ponderosa poles, some oak clumps, and some pinyon and juniper at its western end. This block is on basalt soils and has few living presettlement ponderosa pines.

Block 5: This is the lowest elevation block, containing ponderosa pine mixed with pinyon pine and Utah juniper on basalt soils. This has the most diverse herbaceous component, most likely due to the lower elevation and pinyon/juniper component. Block 5 is still currently being treated, and therefore no data on this block is presented in this report.

Figure 1. The location of experimental blocks 1 - 5



Experimental Block Monitoring Plots

Long-term monitoring is essential to assess current conditions, reconstruct presettlement ecosystem structure, and evaluate the effects of restoration treatments. The standard experimental block monitoring plot is 0.04 ha (0.1 acre) circle (diameter = 22.56 meters), designed with permanent markers to be a long-term monitoring unit. A rebar stake marks the center origin. Plots were adjusted for slope in the field. The plot design measures various components of forest structure, including trees, shrubs, herbaceous plants, forest floor fuels, canopy closure, and photographic records.

Plot origin was determined from a systematic 60-meter grid placed over the sampling site. Twenty gridpoints that fell within the monitoring type were determined as plot origins. The grid was centered in each experimental block unit (treatment or control). The monitoring type specified for this project is ponderosa pine, with at least 10% ponderosa pine forest cover in presettlement times, based on the presence of presettlement-era trees, snags, stumps, or logs. In mixed species stands, ponderosa pine must have been a dominant tree in the stand with old individuals (or remnants) present. A total of 20 plots were sampled per unit, 40 plots per block.

In addition to the larger circular plot, the experimental block plot had an inner circle with diameter of 11.28 meters ($100m^2$) for data sampling purposes. Data collection was divided into 7 major areas:

1. Tree data. All trees greater than breast height were censused on the entire plot (0.04 ha). Each tree censused was tagged and the following data was recorded: diameter at breast height, condition, damage, presettlement/postsettlement field call. Presettlement calls were conservative in the field, and based on a minimal diameter in addition to tree bark color, to ensure any potential presettlement live tree was cored. More accurate calls are made in the lab, after dendrochronological analysis to determine pith date (starting year). All live trees called presettlement in the field were cored, and 10% of all post-settlement live trees were cored for age-distribution data. Regeneration (trees below breast height) was censused in the $100m^2$ inner circle within the plot. Species, condition and height were recorded for each seedling.

2. Dead and downed fuel loadings were collected on each plot using a planar transect (Brown 1974). Fuel load by size class (i.e., Mg/hectare of woody fuels by time-lag fuel moisture size classes: 0 - 1/4 in., 1/4 - 1 in., 1 - 3 in., 3+ in rotten and 3+ in sound), and duff and litter depths were collected along a 50 ft planar transect randomly placed starting from the plot origin.

3. Herbaceous data. The point intercept method was used along a 50 m transect placed through the center of the plot, parallel with the slope. At every 30 cm along this 50 m transect, herbaceous species, species height and substrate were recorded, for a total of 166 points per transect. In addition,

species not seen on the point-intercept transect were recorded in one 10 X 50 meter belt along the herbaceous transect.

4. Shrub data. Shrubs were tallied in the $100m^2$ inner circle by species, condition, and height.

5. Tree canopy cover. The point intercept method was used every 30 cm along the 50 m herbaceous transect (as above, total 166 points) to measure presence or absence of tree canopy.

6. Photopoints. Two photopoints were established at each plot, one from north to center of plot, one from east to center of plot.

7. Reference tree: In case rebar is lost or difficult to find after treatment, a tree which would be retained in the restoration treatment (any tree of presettlement origin is a leave tree) is selected to help relocate the plot origin. For each plot, a presettlement-era live tree was tagged with the distance and bearing to the plot origin.

Experimental Block Sampling

In 1997 and 1998, 20 plots in each unit (total 40 plots per block) were established in all five experimental blocks. All data recorded at this time were pre-treatment. Thinning treatments were implemented in 1999 and 2000. Although treatment prescriptions were the same across blocks, operational differences resulted in differences in each of the blocks. These differences added some difficulty to result interpretation. However, these treatments were representative of on-going treatments occurring at the Trumbull restoration site.

Block 1 was thinned entirely with chainsaws by the BLM fuels crew in the spring of 1999. This block had lower tree densities (around 550 trees per hectare), allowing hand-tool thinning to be feasible. All felled wood was left on site, slash, litter and duff were removed from around the base of pre-settlement era trees, and the site was burned under prescription in the fall of 1999.

Blocks 2 and 3 were thinned by an operator as part of a logging sale (the Cinder sale). Logs greater than 5 inches dbh where removed from site as merchantable wood. Smaller trees were thinned by the fuels crew as part of a pre-fire treatment. Slash, litter and duff were removed from the base of presettlement era trees. Block 2 and 3 were both burned in the spring of 2000.

Unfortunately, a wildfire ignited from a smoking stump in an adjacent prescribed burn. This wildfire torched in a large portion of the control for block 3, and had high flame lengths and intense heat. Even in areas that showed no torching, individual trees suffered up to 100% scorching, thus eliminating that unit as a valid control for the block. As a result, field crews in 2000 initiated a new paired control (referred to as control 2000 throughout text, tables and figures). Although no pre-treatment data were available for the control 2000, tree densities and the herbaceous component were similar to the block 3 treatment unit prior to treatment. The original block 3 control was monitored, and results are reported in the last chapter, Wildfire and Restoration Treatment Results.

Block 4 had the highest tree density (~2500 tph), and this fact combined with accessibility difficulties created operational problems. Initially, the unit was sold as firewood and some wood was removed from the approximately 2 acres cut by the woodcutters. After the woodcutting operation failed, the unit was thinned by contract partially funded by the Ecological Restoration Institute at NAU. As a result, the vast majority of the wood was cut and left on site. With such high tree densities, trees were not thinned to the marked prescription, but rather to a fuel loading maximum. The resulting residual stand following thinning treatments was denser than intended. The unit was burned in prescription in spring 2000, which also fire-killed some of the remaining pines. The treatment in this unit was the most unlike other treatment units at the site.

Block 5 treatment unit was also difficult to access and no thinning operator could be found to implement treatments. As a result, we re-assigned the treatment unit, thus losing the random selection of treatment and control units in this block. Also, the block fell a year behind in the treatment plant, and **so block 5 is excluded from this report**. The unit is currently being thinned, and is scheduled for burning this spring or fall (2001). Future re-monitoring will be included with the other experimental blocks, although the experimental design lacks randomization for this block.

The experimental design allows us to use each block as a replication. Data for many variables are presented with n = 4, i.e., 4 controls and 4 treatments. However, the variability between blocks often masks patterns occurring within blocks. Therefore, we have also included results on a per block basis, to help clarify initial patterns. Data were collected and will be presented in metric units, with corresponding conversions to English units provided in **Appendix 2**.

Chapter 1

Ponderosa pine structural changes through time

Introduction

Landscape-level restoration projects are difficult to replicate or implement with appropriate statistical design (Michener 1997, Hurlbert 1984). At the restoration project in ponderosa pine at the Mt. Trumbull Resource Conservation Area, experimental blocks were established to examine restoration treatments in a replicated fashion, which allows for greater statistical inference. This research design will provide necessary information to assess the impacts of restoration treatments on several ecosystem variables (Eberhardt & Thomas 1991).

In 1870, Euro-American settlers from southern Utah began to utilize the Mt. Trumbull area for grazing and logging purposes. The cessation of fires after 1870 at Mt. Trumbull corresponds to the introduction of livestock by early Euro-American settlers. Heavy grazing is documented to have occurred over the entire Arizona Strip (Altshul and Fairley 1989), severely impacting the understory plant community. As typical of ponderosa pine forests across many areas of the Southwest (Weaver 1951, Cooper 1960, Covington & Moore 1994), the introduced grazing also eliminated the fine fuels (grasses and forbs) that carried the frequent fires throughout the last four centuries. The last recorded fire from fires scars collected at Mt. Trumbull was 1870 (Fulé, unpublished data). Prior to 1870, frequent fires crossed the landscape every 4 to 7 years (Fulé, unpublished data).

The logging industry also impacted the forest structure at Mt. Trumbull post Euro-American settlement. Starting in 1872, the timber was first controlled by the Church of Jesus Christ of Latter Day Saints, for construction of the St. George Temple. Following the completion of the Temple in 1877, the logging operations were run commercially and provided lumber for the developing communities of southern Utah and northern Arizona until the early 1930's (Robert Gardner Diary). The logging industry spanned technology changes from hand-cut logs and horse-powered wood transfer to machine mills and removal by truck. Remains of six mills are known across the Mt. Trumbull site, although more sites are believed to have existed. Mills were owned by 2 or 3 families at any given time, and were moved across the site as merchantable wood was reduced. Although it is difficult to determine how many stems or even board feet were removed from the site, anecdotal stories combined with the archeological findings suggest most of the merchantable wood was removed. Logging operations slowed because of lack of material, and the increased operations on the Kaibab plateau in the 1930's (Roy Hunt, NAU Dep't of Anthropology). In 1935, the forest service built the first ranger station at Mt. Trumbull with wood from the Parashant, which indicates the lack of material on the Trumbull site (Roy Hunt).

Forest structural changes occurred across the arid Southwest as a result of these early Euro-American land use policies. Along with the cessation of fire, the subsequent continued grazing and

removal of old-growth trees allowed serious ponderosa pine tree irruptions to occur over much of the land (Cooper 1960, White 1985, Covington and Moore 1994). Experimentation with returning fire suggests that this process alone is not enough to restore presettlement ecosystem function, and may do further harm to the remaining old-growth trees (Harrington & Sackett 1992, Covington et al. 1994, Covington and Moore 1994). Restoration treatments incorporating overstory tree thinning and returning fire to the land are proposed and have been experimentally implemented on small scales. The Mt. Trumbull restoration project is the first to examine forest structure, understory re-establishment and ecosystem responses on a landscape-level scale to thinning and burning treatments.

Five experimental blocks were established across this landscape in 1997. The experimental blocks represent the variation in forest structure found across the Mt. Trumbull resource conservation area and ranges from low density pine and oak forests to high density pine mixed with pinyon and juniper. This chapter presents forest structure data from experimental blocks 1 - 4 receiving restoration treatments in 1999-2000 (block 5 was not treated by 2000, and is excluded from this report). We compared forest structure as reconstructed to the time of fire exclusion (1870), to stand structure prior to any treatments (1997-1998), and finally to post-treatment stand structure (2000). We specifically examined overstory densities, basal area, tree diameter distributions and tree age distributions. We also look at tree regeneration patterns prior to and following treatment. Fuel loadings and changes with treatment are discussed in this chapter. The herbaceous changes following restoration are discussed in Chapter 3.

Methods

Plot measurement: The experimental and plot design are covered in the general methods section, following the introduction. Circular plots 400m^2 in area (radius = 11.28 meters) were used for tree data collections. Plot areas were corrected for slope in the field. All trees greater than breast height (1.37 m) were measured on the entire plot (400 m^2). Each tree was tagged with an aluminum label at breast height and the following data was recorded: diameter at breast height, crown code (dominant, co-dominant, intermediate or sub-canopy), damage, and condition class (1. live; 2. declining; 3. recent snag; 4. loose bark snag; 5. clean snag; 6. snag broken above breast height; 7. snag broken below breast height; 8. downed dead tree; 9. cut stump, and 10. stump hole). The condition class categories were derived from snag decomposition studies (Thomas et al. 1979). All living and dead trees potentially old and/or large enough to have become established prior to Euro-American settlement (circa 1870) were identified as potentially presettlement trees in the field. Ponderosa pines with dbh > 37.5 cm or ponderosa of any size with yellowed bark (White 1985), as well as all oaks, junipers, and pinyon trees > 17 cm at dbh (Barger & Ffolliott 1972) were considered potentially presettlement trees. All living potentially presettlement trees and 10% of all post-settlement live trees were cored for determination of age and past size. Overstory

canopy cover was measured every 30 cm along one 50 m transect by point intercept method. A total of 166 points per plot were observed. The proportion of points where canopy was present was analyzed.

Seedling trees, those below breast height, were tallied by species, condition, and height class in a nested 100 m^2 circular plot (radius = 5.64 m). Species, condition and height codes (1. < 40 cm; 2. 40.1-80 cm; 3. 80.1-137 cm) were recorded for each seedling.

Fuel loadings were calculated from the planar transect data using methods in Brown (1974) and constants from Sackett (1980). Fuels were sampled on one 50-ft transect on each plot, for a total of 20 transects per unit, and 40 per block.

Tree increment cores were surfaced and crossdated (Stokes and Smiley 1968) with local tree-ring chronologies. Rings were counted on cores which could not be crossdated, especially younger trees. Additional years to the center were estimated with a pith locator (concentric circles matched to the curvature and density of the inner rings) for cores which missed the pith.

Presettlement reconstruction: Presettlement forest structure was reconstructed in 1870, the year in which Euro-American land use practices were introduced to the Mt. Logan area and an approximate date for the cessation of frequent, low-intensity fires in the region (range 1869-1879, see Chapter 2 and P.Z. Fulé and others, unpublished data). Reconstruction of forest structure at an earlier date would have presented greater uncertainty because the frequent fires during this era probably consumed much rotten woody material.

The field determination of presettlement or postsettlement tree status was confirmed or rejected using the age data. For each cored presettlement tree, the radial growth increment from 1870 to collection date was measured on the core and the exclusion year diameter calculated. Species-specific equations developed by Myers (1963) and Hann (1976) in the Southwest were used to estimate bark thickness and to predict dbh based on the inside-bark diameter of stumps. Site-specific regressions were developed from the data set to predict diameter at breast height (dbh) from diameter at stump height (dsh, coring height) for all species.

The year of death of presettlement snags and logs was estimated based on tree diameter and condition class. Dead trees representing the range of condition classes are being crossdated in this and other companion studies in northern Arizona. At the Gus Pearson Natural Area, all dead wood classified in the field as 'presettlement' based on size and decay was of presettlement origin (Mast et al. 1999). However, direct determination of death date was precluded by sapwood rot on almost all of those samples. The harvest date for large stumps (dsh ≥ 40 cm) was assumed to be 1885, corresponding to the historic timber cutting period in the Mt. Trumbull area (Altschul and Fairley 1989), and the date for smaller stumps was assumed to be 1974, corresponding to more recent thinning under Forest Service and BLM management (BLM 1990).

Rates of snagfall and movement through tree decay condition classes were summarized by Rogers et al. (1984). They combined data from Cunningham et al. (1980) and Avery et al. (1976) to calibrate for northern Arizona the tree decomposition model developed by Thomas et al. (1979). Because of high variability among substrates and environmental conditions, as well as the extremely long time span required for research, the dynamics of tree decomposition are poorly understood (Harmon et al. 1985) and mathematical models based on observed decomposition classes are likely to be highly imprecise. To assess the effect of such variability on the presettlement forest reconstruction, we carried out a sensitivity analysis by using three different decomposition rate percentiles, 25%, 50%, and 75%, to examine the effect of slower or faster decomposition on the estimates of death date and ecosystem structure at the date of fire exclusion. Presettlement forest structure based on each of the three percentiles were calculated to determine the relative effect of model imprecision.

To determine the presettlement diameter of dead trees, growth estimates for the period from fire exclusion to death date were subtracted from the measured diameter, adjusted for the loss of bark where appropriate. Site-specific predictive regression relationships between diameter and basal area increment were developed for presettlement ponderosa pine, Gambel oak, and pinyon trees, where an adequate sample size was collected. For Utah juniper, published diameter-dependent growth regression equations were applied to determine presettlement diameter (Barger and Ffolliott 1972).

A potential source of error in this reconstruction approach is missing presettlement-era woody material, which would lead to an underestimate of presettlement forest density. Fire consumption of wood was controlled as much as possible by selecting the year of the last widespread fires in the Mt. Trumbull region as the reconstruction year (although later fires also occurred in parts of the study area). Complete decomposition of resinous woody material in the absence of fire is likely to take longer than the fire exclusion period due to the very slow decomposition rate in arid southwestern forests (Jenny et al. 1949, Hart et al. 1992). Because small-diameter pines rot quickly (Harmon et al. 1985, Arno et al. 1995), it could be argued that small trees or even doghair thickets which were alive in the settlement year but died soon thereafter would be missed. However, there is no evidence in historical accounts, photographs (see 1870 illustration of Mt. Trumbull in Powell [1961:288]), or early inventories for the existence of numerous small trees in presettlement northern Arizona--quite the contrary (Cooper 1960). Nor does it seem likely that such thickets could have become established under frequent fire regimes (White 1985). Finally, there is no reason to believe that such trees would have died in high numbers following fire exclusion, especially in light of the remarkable persistence of small trees in stressed postsettlement doghair thickets (Schubert 1974, Avery et al. 1976, White 1985). The possible underestimation of some small presettlement trees that left no trace cannot be dismissed but such trees are unlikely to have formed a substantial component of presettlement forest structure. A recent study using historical data addressed

this question. Historical plots were revisited, data collected without original data sheets and tree structure reconstructed to the time of original plot establishment (1909 – 1919) (Moore et al. 2001). These data showed 5% - 11% of trees on the original plot were missed by the reconstruction technique, amounting to between 3 and 14 missed trees per hectare (Moore et al. 2001).

Plot remeasurement: Fuels were remeasured in treatment units of Blocks 1 and 2 following the thinning and prior to the burning in 1999, to allow for pre-burn fuel tallies. All plot measurements were sampled the season following prescribed burn (2000). Tree tags and original maps were used to re-locate and re-tag trees, if necessary. Tree remeasurements included tree condition, scorch and char heights. A new condition class was established for trees consumed by fire (cond. 11) and trees previously dead (cond. 3 or above in 1998), that were unable to be relocated (cond. 12). No tree diameters were remeasured, because of minimal growth changes from year to year, and the possibility of negative growth as the result of char and bark loss. Tree regeneration, forest fuels and canopy cover were sampled in all blocks the summer following the burn.

In EB 1, 6 control plots were burned when a burning snag fell across fire lines into the control area. No trees were lost to fire, but because the low intensity burn altered forest fuels and understory, these plots were excluded from post-treatment fuel loading statistical comparisons. Block 2 control also had one plot lost to fire from an adjacent unit which was also excluded from fuel analyses.

Results

Forest structure changes through time: Forest structure at the time of the last widespread fire (1870) was relatively open (61.5 trees per hectare) and was significantly less dense than forests at the time of our initial survey (~1370 tph in 1997-1998, Table 1.1, t-test = 3.3, $p < 0.04$, $n = 4$). Basal area also showed 400% - 600% increases from the presettlement reconstructed forest stand to the 1997 initial survey (Table 1.2, t-test = 6.0, $p < 0.05$, $n = 4$). Presettlement basal area ranged from 4 to 7 m^2/ha, with a high of 13 m^2/ha on the EB2 treatment unit. There were no significant differences in tree density or basal area between control and treatment units in reconstructed data (1870), suggesting that these blocks were very similar in presettlement time, prior to fire suppression. The Mt. Trumbull presettlement tree density and basal area were variable across blocks, but were well within the range of presettlement reconstructions across northern Arizona. The increases in tree density and tree basal area since settlement were also comparable to subsequent changes in other sites across the southwest. In fact, the range of changes since presettlement found in the experimental blocks were indicative of similar differences in changes since presettlement found across northern Arizona. For example, ponderosa pine density ranged from 13 tph in EB4 to 67 tph in EB1, and had increased between 10 and 50 times by 1998.

The composition of the presettlement forest was similar to the contemporary forest in all blocks except Block 4. Stands were dominated by ponderosa pine in both stems per acre as well as basal area in blocks 1 - 3. However, in the 1870 stand of EB4, *Juniperus osteospermus* contributed to half of the stand basal area (total of 3.1m^2/ha) in the control unit (Table 1.2), and almost half the stems in both the control and treatment units (Table 1.1). This block changed from a ponderosa/ juniper ecotone to an almost pure ponderosa pine forest in the time since settlement and fire exclusion. Other compositional change observed in all blocks was the general increase in deciduous tree density, *Quercus gambelii* and *Robinia neomexicana*. These trees are both excellent sprouting trees, and in the absence of periodic fire can develop clumped stands (see age data, below). We hypothesize that under a frequent fire regime, these species were represented by a few established older trees and a large shrub component. However, no data is presented here to support or refute this hypothesis. The reconstruction of deciduous trees may have errors, as mentioned above in the methods. Oaks, in particular, often develop heartrot, and start decomposing long before death. It is more likely that presettlement evidence would be missed for deciduous trees rather than for conifers, specifically ponderosa pine. The deciduous population structure with frequent fire will be monitored as the Trumbull restoration project continues.

Restoration treatment effects on forest structure: The thinning treatment significantly reduced tree density by on average 77%, with 68% of stems removed in EB2, and 85% of stems removed in EB3 (Table 1.1, year 2000). Basal area was decreased by 48% on average, with a range of 35% removed in EB1 to 58% removed in EB3 (Table 1.2, year 2000). However, both post-treatment tree density and basal area were significantly greater than the presettlement reconstructed tree density and basal area (Table 1.1, 1.2, t-test, $p > 0.05$). Restoration treatments were designed to leave more trees than presettlement reconstructed densities, to account for the smaller biomass contributed by smaller diameter trees, potential errors in reconstructions, and to allow for un-predicted mortality due to restoration treatments. The treated blocks have between 2 and 15 times as many tree stems as the reconstructed, presettlement stands.

The stem density and basal area reduction post-treatment represent a shift in the diameter distributions of the units following treatment (Fig. 1.1a-d). Figure 1 depicts diameter distributions of control and treatment units in reconstructed presettlement stands, contemporary stands prior to treatment, and contemporary stands following treatment (a. Block 1, b. Block 2, c. Block 3, d. Block 4). In 1997, approximately 40% of living trees were between 0 and 5cm diameter at breast height (dbh). Almost 75% of living ponderosa pine trees were below 25cm at dbh. This pattern is an inverse growth curve, and is often found in self-thinning forests. However, as noted in the reconstructed diameter distribution, a more natural distribution in ponderosa pine would consist of a statistically normal distribution of diameters (note scale change between reconstructed forests and contemporary forests, Fig. 1). Following treatment

(treatment unit, bottom row), the diameter distribution does show a distribution comparable to the reconstructed (1870) diameter distribution, although total trees per hectare is higher. Ninety percent of the ponderosa pines thinned were taken from diameter classes less than 35 cm at breast height.

Age structure: Age distributions for each control and treatment unit within each block are shown in Figure 1.2. Although there was variation between blocks in age distributions (note graph scales), 94% – 99% of ponderosa pine trees had center dates later than 1870, and therefore established since the time of the last widespread fire. This ponderosa pine regeneration boom quickly dropped in the 1950 age class (1940 – 1960); a much smaller proportion of trees established in these decades. The youngest trees of the stand were composed of deciduous oaks and locust. Also noticeable in the blocks was a pulse of oaks in the 1870 age class (1860 – 1880). This pulse is most likely due to the cessation of fires, which allowed the sprouting oak to reach tree stature. These age distributions are comparable to other sites in the Southwest and Mexico (Fulé et al. 1997, Covington et al. 1997).

Following treatment, the age distribution was altered with the removal of large proportions of the postsettlement (post 1870) age classes (Fig. 1.3). Although the post-treatment age distributions are still skewed towards younger age classes, the proportion of trees with smaller age classes has been significantly reduced. Trees with center dates greater than 1870 composed ~70% of the trees in blocks 1 and 3, and 90% of the trees in block 2, mostly due to oaks. Block 4 is still predominately post-settlement trees (99%). No live trees with ages prior to 1870 were removed by the thinning treatment.

Canopy cover: Following treatment, canopy cover was significantly reduced between 20% and 44% in treated units (paired t-test = 4.62, $p < 0.05$). Canopy cover averaged 56% across all blocks in the pre-treatment sampling years of 1997 and 1998 (Table 1.3). Post-treatment canopy cover ranged from 22% in eb3 to as high as 53% in eb4. Canopy cover is correlated with trees per hectare, but also gives an indication of tree biomass. We expect canopy cover to be indirectly related to understory production, as shown in other studies (Moore and Dieter 1992).

Regeneration: Regeneration of tree species showed no significant differences following restoration treatment when analyzed across all blocks ($n = 4$, $t = -1.53$, $p > 0.05$). Variation within units was high when examined by block (Table 1.4). The only tree species with regeneration present in all four blocks was ponderosa pine, and this species showed no immediate response to the restoration treatment (Fig. 1.4). In fact, although not significant, this species declined in both control and treatment units from 1997 to 2000, suggesting other environmental factors contributed to regeneration rates.

The experimental blocks were set up to represent the range of variation in ponderosa pine stands found across the Mt. Trumbull site and do not have identical tree composition (see Table 1.1). The experimental design will test effectively the differences in variables well represented in each block, such as ponderosa pine tree density, fuel loadings and understory cover. However, Gambel oak and New

Mexican locust are not equally represented in the blocks, and therefore, we do not have the replication to adequately test effects of restoration treatment on these species.

Fuels: Total fuel loadings were high prior to treatments, ranging from a low of 16 Mg/ha (metric tons per hectare) in EB3 to a high of 64 Mg/ha in EB2 (Table 1.5). Fuels averaged 34 Mg/ha prior to treatment across the entire site. Forest floor depths ranged from 2 cm to 5 cm. These depths and loadings are comparable to other sites located across the Southwest (Fulé et al. 1997) and represent the range of fuel loadings at Mt. Trumbull. Although the fuels were variable across the site, no significant differences were found between treatments within blocks prior to treatments.

Total pre-burn woody fuels did not significantly increase following the thinning treatment (Table 1.5, treatment status = Pre-burn).. In fact, pre-burn fuels actually showed a declining trend in EB1 following thinning treatments. EB2 showed a pattern of increasing fuel following the thinning treatment, although this was also not significant. These two reflect the overall variability of the woody fuels and the sampling transects (note the high standard error values in Table 1.5).

Significant fuel depth reduction occurred in treatment units across blocks in litter and duff layers. Significant increases were found in 100 hour fuels and 1000 hours sound fuels (Figure 1.5, MANOVA, $p < 0.05$).

Discussion

Structural changes since last known fire: Forest structure showed significant increases in tree density and basal area since the date of the last known fire at the Mt. Trumbull restoration cite (1870). On average, 1998 tree densities were 25 times higher than 1870 densities. Ponderosa pine densities were 13 times as high in 1998 in blocks 1 – 3, but EB4 saw astronomical increases, with ponderosa pine more than 100 times as dense in 1998 (1700 tph) than in 1870 (14 tph). This is characteristic of many Southwest forests where dense forest stands established after interruption of the fire regime (Cooper 1960, White 1985, Covington et al. 1994). Although heavily logged, there remain some large diameter trees in the current stands across the site. Studies have shown these trees are stressed under current dense conditions, and are more susceptible to disease and insect attack (Covington et al. 1997, Kolb et al. 1994).

Forest composition did not change noticeably in 3 of 4 blocks and stands were dominated by ponderosa pine. However, EB4 saw compositional changes from a pinyon-juniper- ponderosa pine ecotone to an almost pure ponderosa pine stand. Forest ecotones are the first systems to show compositional changes as the processes that determine species distributions (i.e., fire) are disrupted. Ecotones changes may serve as good indicators of forest health changes. Many higher elevation ponderosa pine reconstruction studies show compositional changes, with encroachment and density increases observed by Douglas fir and white fir (Heinlein 1996, Moore et al. 2001). This study suggests

comparable changes can be found at the lower elevation ecotones, with ponderosa pine expansion into pinyon-juniper woodlands.

Structural changes due to restoration treatments: The first year post-treatment restoration experiment was successful in reducing tree density while maintaining the larger diameter classes and older trees (see chapter 4 for comparison with wildfire treatment). We showed that these restored densities remain significantly higher than reconstructed pre-settlement densities. Plausible critiques of the reconstruction procedure are that small diameter trees may be missed (although see methods for this discussion). Tests of the reconstruction methodology using plots established and inventoried in 1909 showed that missed presettlement evidence could result in a 5% – 11% underestimate of tree density, or between 3 and 14 missed trees per hectare (Moore et al. 2001). Leaving higher numbers of trees in the restoration treatments allows for this level of uncertainty in the reconstruction methodology. In this case, tree densities in restored units were between 100% and 1000% (EB4) higher than reconstructed presettlement tree densities, providing density buffers well above the 11% error rate found in Moore et al.'s study (2001). However, these densities will continue to change through time as unplanned mortality may continue to lower tree densities in the restored units. Mortality due to fire can take up to 5 years to become evident (Sackett et al. 1996). Conversely, trees that have up to 90% scorch have been shown to survive (Dietrich 1979). Current observations show increased mortality of old-growth trees in EB 1 in the second year following restoration treatments. This unit is located on lava soils which may contribute to differential old-growth response to fires. Currently, all prescribed fire on lava flows/ soil have been halted, pending further research.

The initial burn was not similar to presettlement fires, as it was utilized operationally to remove slash. This initial burn easily consumed the highly flammable aerial slash, including needles and small twigs. However, sound small diameter logs may take several fires until mostly consumed and will remain on the ground following treatment. These fuels left after thinning were highly variable, resulting in no apparent significant differences found between the pre-treatment fuels and the post-thin, pre-burn fuels. When fuel loadings are examined by fuel size categories, patterns do emerge. For example, following the prescribed burn, fuel loadings showed decreases in the finer fuels (litter and duff depths), but showed significant increases in larger diameter fuels. Although there were fuel compositional changes, the total fuel loadings did not show significant changes across the four blocks with restoration treatment.

These data suggest several goals were accomplished in the first year following treatment. Tree density reduction reduced the threat of crownfire (see Chapter 2), and much of the accumulated fine fuel was removed. Several attributes that are monitored in the restoration treatments will not show effects for several years. For example, tree regeneration was variable and showed no differences in the first year following treatment, but may show increases 2 to 3 years following treatment, and then large declines

with subsequent burning. These responses will vary between conifers and deciduous species. Fuel loadings may show total fuel differences, as well as compositional changes through time.

This treatment cannot replicate the presettlement forest or undo long-term degradation, such as logging and grazing. Old growth trees are limited at the Mt. Trumbull site, and replacement post-settlement trees will not contribute to forest structure in similar ways for decades or even centuries. However, this treatment is a management option that can restore characteristics of the presettlement forest, such as more open stands, which may help prevent future damage from uncharacteristic crown fires. Future degradation can still occur. Cattle grazing and recreation will continue to impact the land, and only through future monitoring will the effects of these restoration treatments combined with future uses be understood.

Implications: Long-term goals of these ecological restoration projects will continue to be assessed through time. These restoration treatments are hypothesized to increase biodiversity. However, the single-species responses to restoration treatments have not been specifically hypothesized, because of the little work available on habitat preferences. As a result, species guilds, such as song-birds, reptiles, butterflies and small mammals, are being examined to determine their short and long-term effects. These replicated experiments are the first in ponderosa pine restoration at this scale, and will provide the information necessary to directly impact the management decisions in ponderosa pine forests.

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Table 1.1. Tree density (trees/ha) at Mt Trumbull study sites in 1870 (reconstructed), 1997-98 (pre-treatment), and 2000 (post-treatment). Statistics presented are the mean and standard error. The mean is in bold and the standard error is in parentheses. Species codes are derived from the first two letters of the Genus and Species (e.g. JUOS = *Juniperus osteosperma*).

Block	Treatment	Date	Total	JUOS	PIED	PIPO	QUGA	RONE
1	Control	1870	**67.5** (9.3)			**65.0** (9.8)	**2.5** (2.5)	
		1997-98	**691.3** (93.7)		1.3 (1.3)	**608.8** (89.6)	**70.0** (54.9)	**11.3** (11.3)
		2000	**682.5** (93.7)			**607.5** (89.6)	**67.5**(54.9)	**7.5** (7.5)
1	Treatment	1870	**61.3** (7.6)			**53.8** (7.5)	**7.5** (5.5)	
		1997-98	**593.8** (100.3)			**476.3** (78.8)	**117.5** (80.8)	
		2000	**125.0** (25.7)			**90.0** (11.9)	**35.0** (20.5)	
2	Control	1870	**77.5** (13.8)			**53.8** (10.8)	**23.8** (8.0)	
		1997-98	**1375.0** (234.3)	**13.8** (9.0)		**681.3** (108.0)	**611.3** (173.5)	**68.8** (32.8)
		2000	**1262.5** (207.6)	**13.8** (9.0)		**652.5** (98.0)	**547.5** (152.9)	**48.9** (26.3)
2	Treatment	1870	**106.3** (20.1)			**20.0** (9.4)	**86.3** (20.0)	
		1997-98	**1723.8** (421.4)	**2.5** (1.7)	**6.3** (3.6)	**276.3** (70.5)	**507.5** (128.7)	**931.3** (456.1)
		2000	**568.8** (135.6)	**1.3** (1.3)	**2.5** (2.5)	**46.3** (8.2)	**296.3** (85.4)	**222.5** (135.6)
3	Control*	1870	**26.3** (5.3)			**22.5** (5.4)	**3.8** (2.7)	
		1997-98	**951.3** (192.3)	**1.3** (1.3)	**6.3** (3.1)	**507.5** (134.2)	**43.8** (22.9)	**392.8** (171.7)
3	Treatment	1870	**48.8** (8.0)			**40.0** (6.9)	**8.8** (3.3)	
		1997-98	**877.5** (127.4)	**1.3** (1.3)	**1.3** (1.3)	**621.3** (123.8)	**52.5** (29.2)	**201.3** (100.5)
		2000	**140.0** (27.2)			**100.0** (24.5)	**18.8** (9.4)	**21.3** (18.8)
3	Control 2000*	1870	**82.5** (23.6)			**45.0** (8.2)	**37.5** (22.7)	
		2000	**737.5** (136.1)	**3.8** (2.7)	**2.5** (1.7)	**612.5** (141.0)	**42.5** (18.8)	**76.3** (33.2)
4	Control	1870	**46.3** (16.8)	**21.3** (8.8)	**10.0** (10.0)	**13.8** (4.6)	**1.3** (1.3)	
		1997-98	**2475.0** (198.2)	**250.0** (57.5)	**122.5** (33.4)	**1665.0** (255.8)	**411.3** (91.1)	**26.3** (15.2)
		2000	**2377.5** (162.5)	**250.0** (57.3)	**120.0** (32.3)	**1626.3** (246.0)	**357.5** (82.6)	**23.8** (14.4)
4	Treatment	1870	**35.0** (10.2)	**13.8** (5.3)	**5.0** (5.0)	**13.8** (3.4)	**2.5** (1.7)	
		1997-98	**2350.0** (159.7)	**191.3** (37.9)	**37.5** (12.9)	**1712.5** (153.5)	**395.0** (110.9)	**13.8** (10.2)
		2000	**521.25** (61.6)	**26.3** (11.4)	**7.5** (4.5)	**460.0** (55.2)	**27.5** (9.6)	

Table 1.2. Basal Area (m^2/ha) at Mt Trumbull study sites in 1870 (reconstructed), 1997-98 (pre-treatment), and 2000 (post-treatment). The mean is presented in bold and the standard error is in parentheses. Species codes are derived from the first two letters of the Genus and Species (e.g. JUOS = *Juniperus osteosperma*).

Block	Treatment	Date	Total	JUOS	PIED	PIPO	QUGA	RONE
1	Control	1870	**7.0** (1.5)			**7.0** (1.5)	**0.004** (0.004)	
		1997-98	**26.9** (2.3)		**0.002** (0.002)	**26.7** (2.4)	**0.2** (0.2)	**0.02** (0.02)
		2000	**27.0** (2.3)			**26.8** (2.4)	**0.2** (0.2)	**0.008** (0.008)
1	Treatment	1870	**5.7** (0.9)			**5.6** (0.9)	**0.02** (0.02)	
		1997-98	**23.7** (1.7)			**23.2** (1.7)	**0.5** (0.4)	
		2000	**15.5** (1.7)			**15.2** (1.7)	**0.3** (0.2)	
2	Control	1870	**13.8** (3.3)			**13.7** (3.4)	**0.1** (0.05)	
		1997-98	**36.1** (2.8)	**0.1** (0.07)		**31.6** (2.7)	**4.4** (0.9)	**0.03** (0.03)
		2000	**35.6** (2.7)	**0.1** (0.07)		**31.3** (2.6)	**4.2** (0.9)	**0.03** (0.03)
2	Treatment	1870	**4.6** (1.6)			**4.1** (1.6)	**0.5** (0.2)	
		1997-98	**28.2** (3.8)	**0.005** (0.004)	**0.03** (0.02)	**17.5** (3.1)	**10.3** (2.7)	**0.3** (0.1)
		2000	**14.9** (2.5)	**0.002** (0.002)	**0.01** (0.01)	**7.5** (2.1)	**7.3** (2.0)	**0.06** (0.04)
3	Control*	1870	**5.7** (1.7)			**5.7** (1.7)	**0.002** (0.001)	
		1997-98	**30.4** (3.8)	**0.09** (0.09)	**0.2** (0.09)	**29.5** (3.9)	**0.6** (0.3)	**0.04** (0.02)
3	Treatment	1870	**9.2** (2.1)			**9.1** (2.2)	**0.08** (0.06)	
		1997-98	**39.7** (4.3)	**0.01** (0.01)	**0.04** (0.04)	**38.3** (4.5)	**1.0** (0.4)	**0.4** (0.4)
		2000	**17.0** (3.6)			**16.1** (3.7)	**0.4** (0.2)	**0.4** (0.4)
3	Control 2000*	1870	**6.7** (1.4)			**6.4** (1.4)	**0.3** (0.2)	
		2000	**27.0** (3.1)	**0.02** (0.02)	**0.01** (0.01)	**25.4** (3.1)	**1.4** (0.7)	**0.2** (0.1)
4	Control	1870	**6.4** (1.6)	**3.1** (1.3)	**0.3** (0.3)	**3.0** (1.2)	**0.003** (0.003)	
		1997-98	**44.6** (3.0)	**3.9** (1.4)	**1.1** (0.9)	**38.4** (3.7)	**1.2** (0.4)	**0.007** (0.004)
		2000	**44.2** (3.0)	**3.7** (1.2)	**1.1** (0.9)	**38.3** (3.7)	**1.1** (0.4)	**0.009** (0.006)
4	Treatment	1870	**7.5** (2.0)	**1.2** (0.7)	**0.05** (0.05)	**6.2** (2.0)	**0.09** (0.08)	
		1997-98	**50.3** (1.8)	**2.3** (0.5)	**0.4** (0.3)	**46.3** (2.1)	**1.3** (0.3)	**0.003** (0.003)
		2000	**26.4** (2.3)	**0.8** (0.5)	**0.08** (0.05)	**25.3** (2.2)	**0.2** (0.09)	

Table 1.3 % Canopy cover (mean (s.e.))

	Pre-treatment (1997 – 1998)		Post-treatment (2000)	
	Control	**Treatment**	**Control**	**Treatment**
Block 1	**50.6** (2.93)	**35.6** (2.91)	**56.6** (3.57)	**26.9** (2.35)
Block 2	**62.7** (3.17)	**55.5** (4.15)	**63.9** (3.28)	**39.0** (3.85)
Block 3	**47.6** (4.55)	**49.3** (4.81)	**47.9** (4.19)	**21.5** (3.57)
Block 4	**70.5** (2.46)	**74.4** (3.58)	**73.8** (2.30)	**52.5** (4.42)

Table. 1.4. Tree regeneration in trees/hectare across the four blocks by species and height class.

			Pre-treatment (1997 – 1998)				Post-treatment (2000)			
Block	**Treatment**	**Species**	**Total**	**0 – 40 cm**	**40 – 80 cm**	**80 – 137 cm**	**Total**	**0 – 40 cm**	**40 – 80 cm**	**80 – 137 cm**
1	Control	PIPO	75 (26.0)	45 (18.5)	10 (10.0)	20 (11.7)	45 (19.8)	35 (18.1)	5 (5)	5 (5)
		QUGA	25 (17.6)	15 (10.9)	5 (5)	5 (5)	95 (31.2)	75 (22.8)	15 (15)	5 (5)
		RONE	25 (16.0)	5 (5)	15 (10.9)	5 (5)	35 (30.1)	10 (10)	20 (20)	5 (5)
1	Treatment	PIPO	170 (66.5)	10 (6.9)	70 (17.9)	90 (55.2)	20 (9.1)	10 (6.9)	10 (6.9)	0
		QUGA	215 (150.8)	150 (99.9)	65 (51.4)	0	235 (131.0)	130 (130.0)	5 (5)	0
		PIED	5 (5)	5 (5)	0	0	0	0	0	0
2	Control	PIPO	55 (15.4)	10 (6.9)	35 (13.1)	10 (6.9)	40 (13.4)	15 (8.19)	15 (8.19	10 (6.9)
		QUGA	4240 (1415.0)	2510 (905.3)	1260 (434.3)	470 (171.1)	2925 (1071.0)	2275 (804.3)	705 (325.5)	260 (123.2)
		RONE	110 (58.4)	60 (39.3)	45 (30.3)	5 (5)	360 (200.4)	215 (158.0)	110 (69.5)	45 (31.2)
		JUOS	10 (10)	0	10 (10)	0	15 (15)	5 (5)	0	10 (10)
		PIED	20 (11.7)	10 (6.9)	5 (5)	5 (5)	25 (14.3)	15 (10.9)	5 (5)	5 (5)
2	Treatment	PIPO	85 (30.2)	330 (10.5)	35 (18.2)	20 (9.2)	15 (15)	0	5 (5)	10 (10)
		QUGA	3125 (1349.0)	2055 (829.4)	870 (386.3)	200 (155.6)	3480 (1702.0)	3405 (1682.7)	70 (42.4)	5 (5)
		RONE	1089 (431.1)	305 (148.1)	490 (200.0)	285 (130.0)	1400 (477.6)	1015 (377.4)	255 (91.0)	150 (105.0)
		PIED	5 (5)	5 (5)	0	0	0	0	0	0
3	Control*	PIPO	25 (12.3)	10 (6.9)	5 (5)	10 (10)	95 (25.6)	35 (16.7)	45 (11.4)	15 (8.2)
		QUGA	15 (8.2)	15 (8.2)	0	0	710 (570.6)	690 (561.2)	20 (13.8)	0
		RONE	2410 (1030)	745 (404.1)	1090 (517.8)	575 (213.8)	225 (121.2)	75 (42.8)	85 (41.8)	65 (45.5)
		PIED	5 (5)	0	5 (5)	0	10 (6.9)	5 (5.0)	5 (5.0)	0
3	Treatment	PIPO	30 (20.6)	20 (15.6)	5 (5)	5 (5)	0	0	0	0
		QUGA	100 (47.6)	100 (47.6)	0	0	110 (64.0)	105 (59.6)	5 (5.0)	0
		RONE	685 (380.1)	255 (171.9)	295 (161.3)	135 (67.8)	1300 (685.7)	1015 (535.7)	265 (147.5)	20 (11.7)
		PIED	5 (5)	5 (5)	0	0	5 (5.0)	5 (5.0)	0	0
4	Control	PIPO	175 (154.4)	170 (154.6)	0	5 (5)	10 (10)	5 (5.0)	5 (5.0)	0
		QUGA	3835 (1477)	2825 (1181.2)	720 (256.1)	290 (107.1)	2965 (1166.0)	2070 (817.8)	705 (319.3)	190 (73.6)

Block	Treatment	Species	Pre-treatment (1997 – 1998)				Post-treatment (2000)			
			Total	0 – 40 cm	40 – 80 cm	80 – 137 cm	Total	0 – 40 cm	40 – 80 cm	80 – 137 cm
		RONE	**70** (45.4)	**50** (40.1)	**10** (6.9)	**10** (6.9)	**55** (24.6)	**15** (10.9)	**25** (14.3)	**15** (8.2)
		JUOS	**100** (38.4)	**75** (34.7)	**15** (10.9)	**10** (6.9)	**40** (22.2)	**30** (17.9)	**0**	**10** (6.9)
		PIED	**35** (15)	**25** (12.3)	**10** (6.9)	**0**	**70** (19.3)	**40** (13.4)	**30** (12.8)	**0**
4	**Treatment**	PIPO	**45** (23.5)	**5** (5)	**30** (17.9)	**10** (6.9)	**0**	**0**	**0**	**0**
		QUGA	**5675** (1631.0)	**3430** (1007.3)	**1760** (500.7)	**485** (197.1)	**3140** (916.1)	**3105** (911.7)	**35** (24.4)	**0**
		RONE	**15** (10.9)	**0**	**5** (5)	**10** (6.9)	**5** (5.0)	**0**	**5** (5.0)	**0**
		JUOS	**65** (22.1)	**30** (12.8)	**35** (15.0)	**0**	**0**	**0**	**0**	**0**
		PIED	**25** (25)	**25** (25)	**0**	**0**	**0**	**0**	**0**	**0**

Table 1.5. Forest floor depth and woody debris biomass at Mt Trumbull study sites before and after restoration treatment. The statistics presented are the mean and standard error. The mean is presented in bold and standard error is presented in parentheses. Woody fuels are classified by moisture timelag class (1H = 1 hour timelag, etc.). Blocks 1-2 and 2-2 contain two pre-treatment data sets. The first data set, pre-thin, was collected before thinning and burning occurred. The second data set, pre-burn, was collected after thinning

Block	Treatment	Treatment Status	Litter (cm)	Duff (cm)	1H (Mg/ha)	10H (Mg/ha)	100H (Mg/ha)	1000H sound (Mg/ha)	1000H rotten (Mg/ha)	Total Wood (Mg/ha)
1	**Control**	Pre-treat	**0.73** (0.08)	**4.40** (0.66)	**0.70** (0.29)	**1.89** (0.38)	**3.30** (1.05)	**18.1** (10.8)	**4.06** (3.30)	**28.1** (10.9)
		Post-treat	**1.22** (0.17)	**3.03** (0.49)	**0.17** (0.04)	**1.01** (0.26)	**2.86** (1.24)	**4.62** (4.46)	**0.41** (0.28)	**9.01** (5.04)
1	**Treatment**	Pre-thin	**0.48** (0.05)	**1.70** (0.23)	**0.22** (0.08)	**0.90** (0.14)	**1.58** (0.84)	**48.9** (28.0)	**12.6** (8.18)	**64.2** (28.2)
		Pre-burn	**2.87** (0.86)	**2.72** (0.30)	**0.36** (0.13)	**2.60** (0.65)	**4.17** (1.55)	**28.8** (6.30)	**4.52** (4.52)	**40.4** (7.05)
		Post-treat	**0.32** (0.04)	**1.67** (0.17)	**0.23** (0.07)	**1.06** (0.20)	**6.47** (1.31)	**11.4** (4.07)	**12.3** (5.97)	**32.9** (6.88)
2	**Control**	Pre-treat	**0.75** (0.06)	**2.61** (0.25)	**0.22** (0.07)	**1.82** (0.60)	**2.87** (0.75)	**14.4** (8.51)	**13.8** (9.92)	**33.1** (12.2)
		Post-treat	**2.23** (0.23)	**2.32** (0.34)	**0.23** (0.09)	**1.31** (0.32)	**2.26** (0.56)	**12.5** (5.87)	**7.05** (3.20)	**23.4** (6.24)
2	**Treatment**	Pre-thin	**1.17** (0.16)	**2.62** (0.47)	**0.23** (0.06)	**1.41** (0.25)	**2.43** (0.67)	**42.9** (40.2)	**8.28** (7.33)	**55.2** (47.4)
		Pre-burn	**1.32** (0.16)	**2.70** (0.46)	**0.27** (0.06)	**2.79** (0.64)	**8.74** (1.54)	**50.8** (26.7)	**11.3** (11.2)	**74.0** (28.2)
		Post-treat	**0.90** (0.17)	**0.78** (0.13)	**0.20** (0.06)	**1.05** (0.26)	**4.44** (0.92)	**17.6** (9.22)	**0.23** (0.16)	**23.5** (9.26)
3	**Control***	Pre-treat	**0.83** (0.10)	**4.17** (0.38)	**0.33** (0.08)	**2.33** (0.39)	**2.15** (0.85)	**13.9** (9.30)	**9.20** (5.78)	**27.9** (14.3)
3	**Treatment**	Pre-treat	**0.88** (0.12)	**4.06** (0.50)	**0.14** (0.05)	**1.49** (0.43)	**1.58** (0.49)	**4.04** (1.62)	**9.25** (5.62)	**16.5** (5.91)
		Post-treat	**0.47** (0.06)	**1.05** (0.14)	**0.11** (0.03)	**1.25** (0.29)	**3.88** (0.87)	**15.0** (3.73)		**20.3** (4.01)
3	**Control 2000***	Post-treat	**1.92** (0.28)	**3.87** (0.57)	**0.27** (0.06)	**0.89** (0.19)	**1.58** (0.49)	**3.86** (2.21)	**14.4** (9.44)	**21.0** (11.6)
4	**Control**	Pre-treat	**0.82** (0.10)	**3.74** (0.38)	**0.44** (0.14)	**2.64** (0.62)	**3.72** (1.62)	**10.3** (4.69)	**4.68** (3.78)	**21.7** (7.21)
		Post-treat	**2.21** (0.21)	**3.39** (0.34)	**0.45** (0.17)	**1.19** (0.31)	**6.72** (3.49)	**4.19** (2.05)	**20.1** (15.1)	**32.6** (15.8)
4	**Treatment**	Pre-treat	**1.15** (0.10)	**3.44** (0.26)	**0.40** (0.11)	**2.40** (0.56)	**3.58** (1.17)	**21.1** (11.6)	**1.79** (1.79)	**29.2** (12.4)
		Post-treat	**1.45** (0.31)	**2.11** (0.23)	**0.31** (0.09)	**1.65** (0.48)	**9.30** (1.71)	**32.6** (6.67)	**1.55** (1.11)	**45.4** (6.90)

Figure 1.1

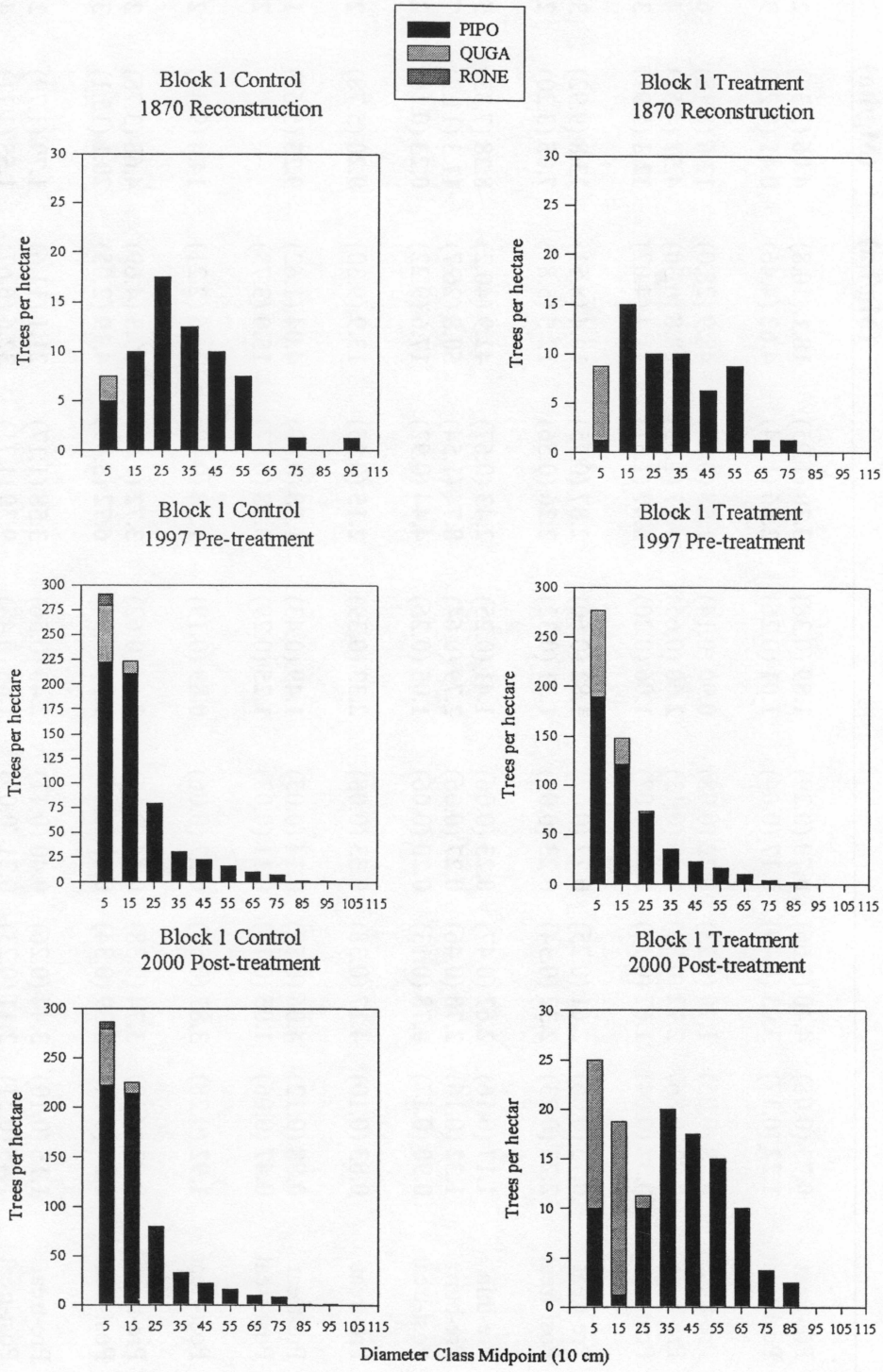

PIPO
QUGA
RONE
Block 1 Control
1870 Reconstruction
Block 1 Treatment
1870 Reconstruction
Block 1 Control
1997 Pre-treatment
Block 1 Treatment
1997 Pre-treatment
Block 1 Control
2000 Post-treatment
Block 1 Treatment
2000 Post-treatment
Trees per hectare
Trees per hectar
Diameter Class Midpoint (10 cm)

Figure 1.1, cont. Block 2

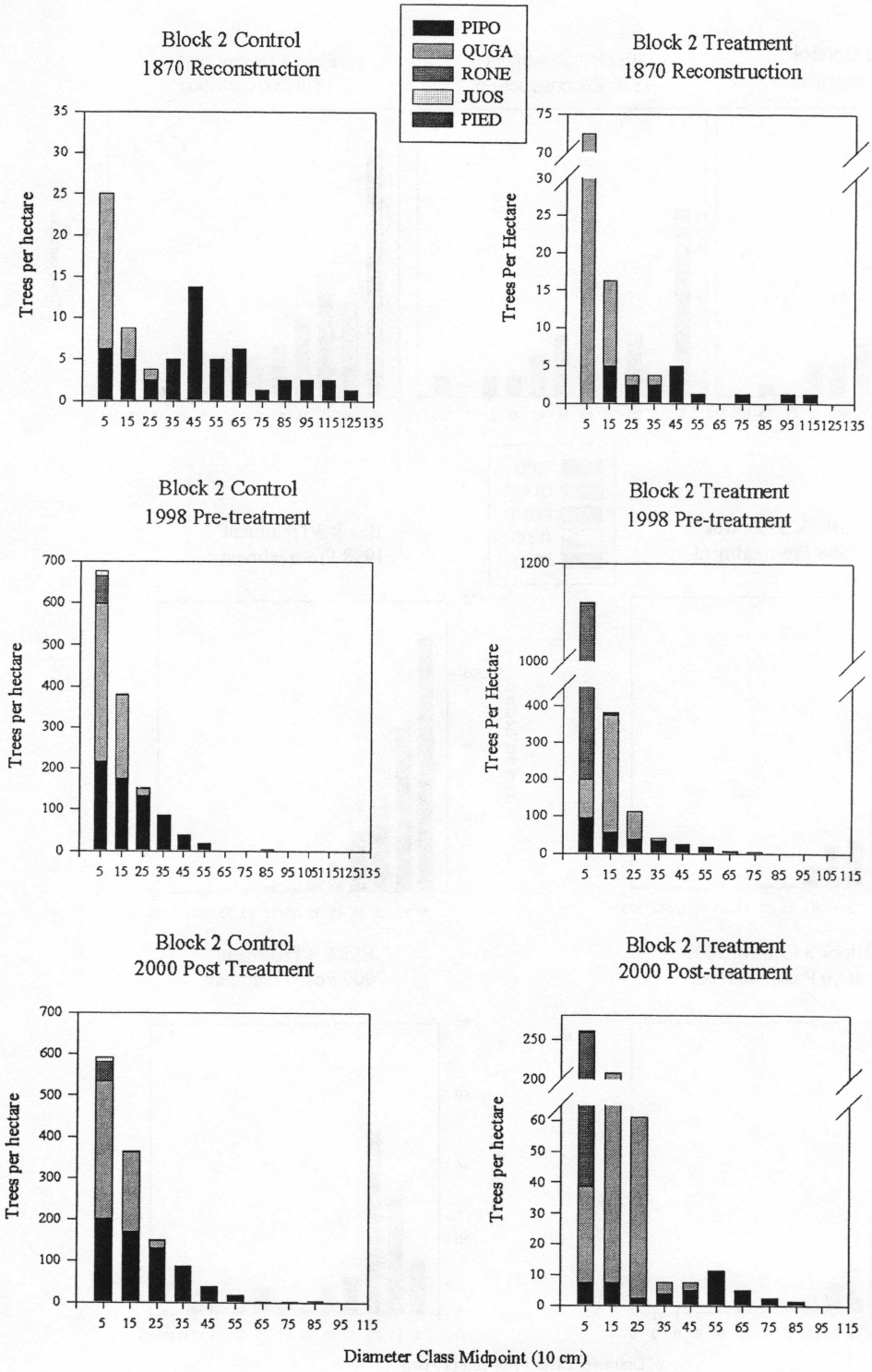


Figure 1.1, cont. Block 3

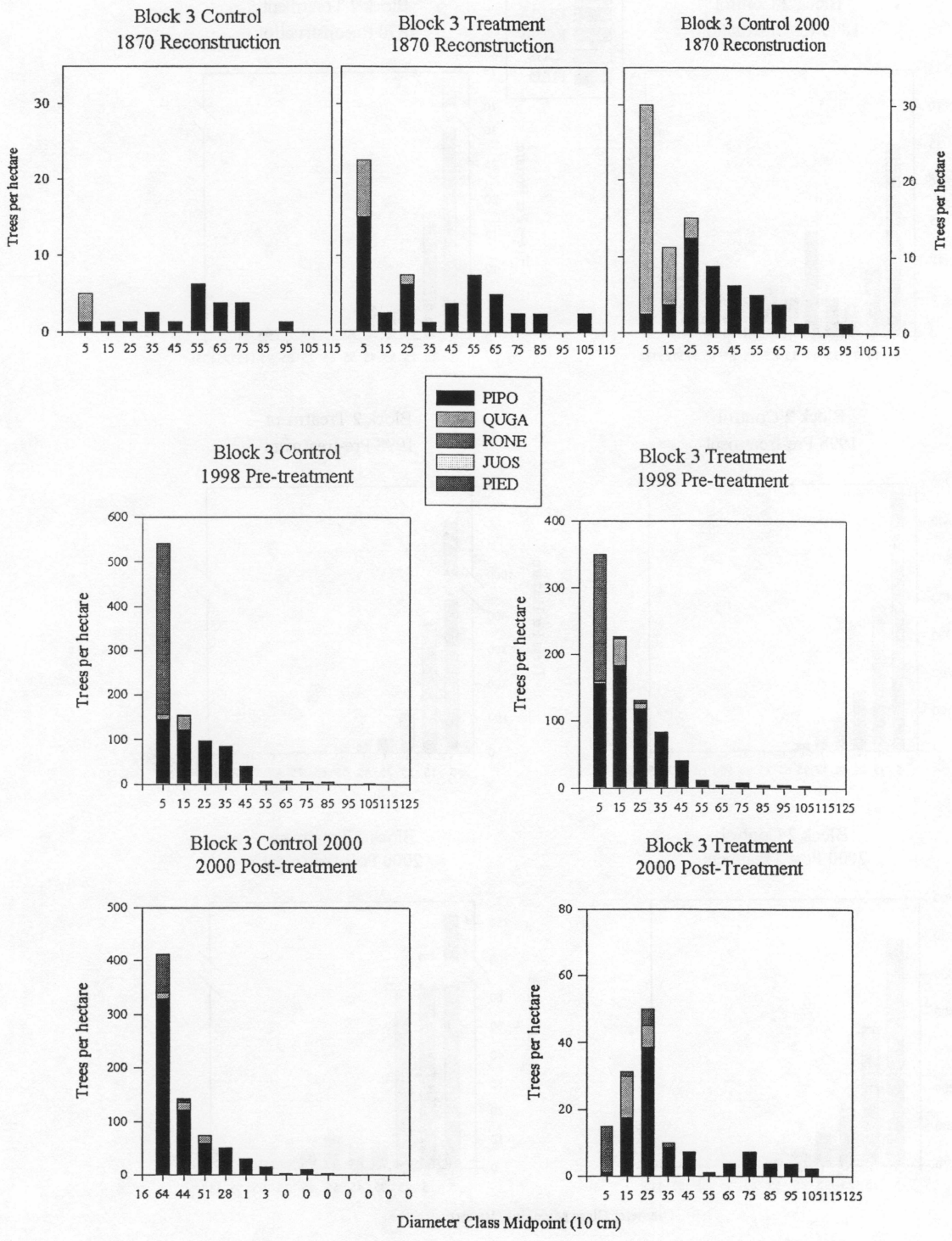


Figure 1.1, cont. Block 4

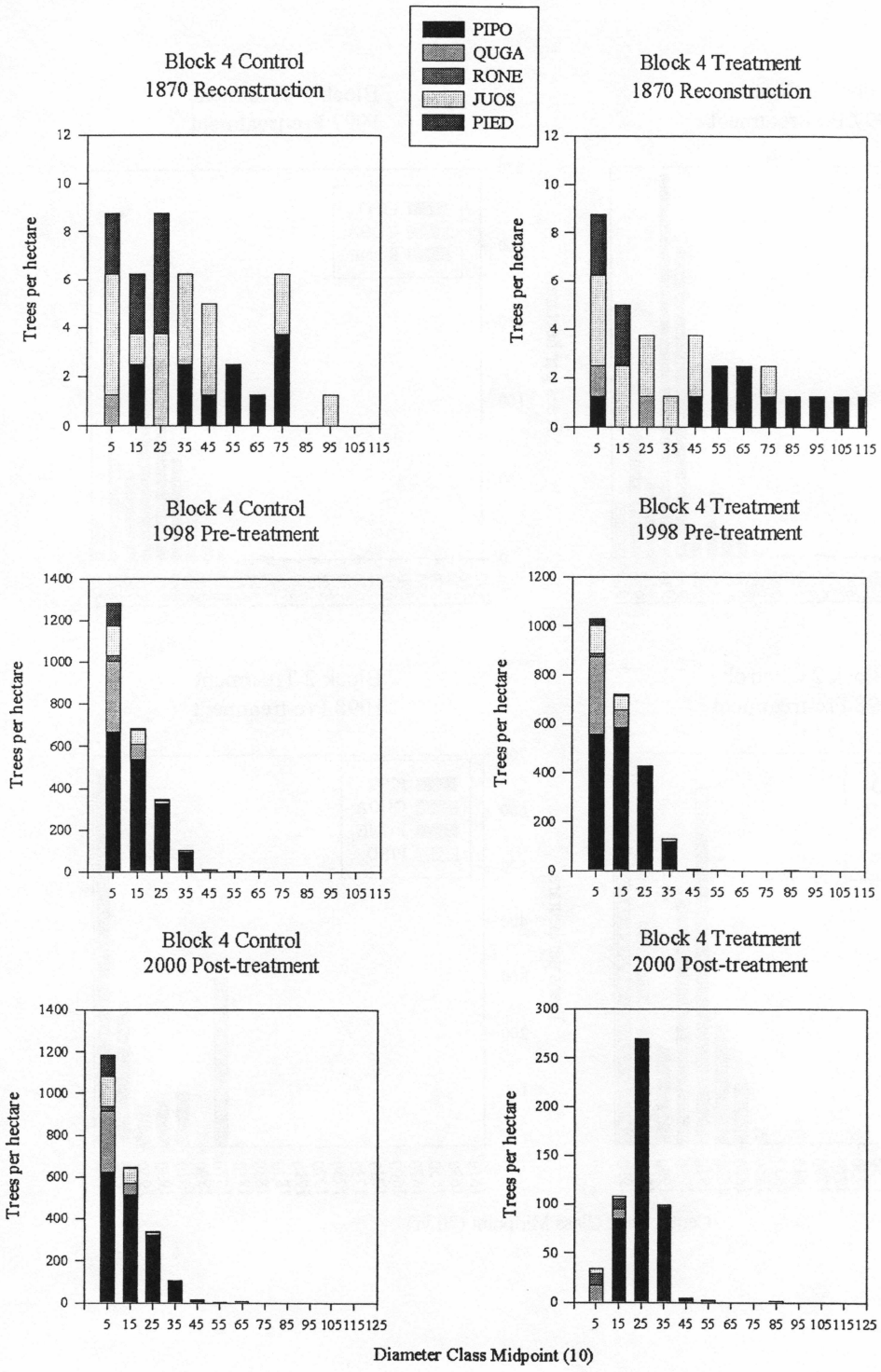


Figure 1.2

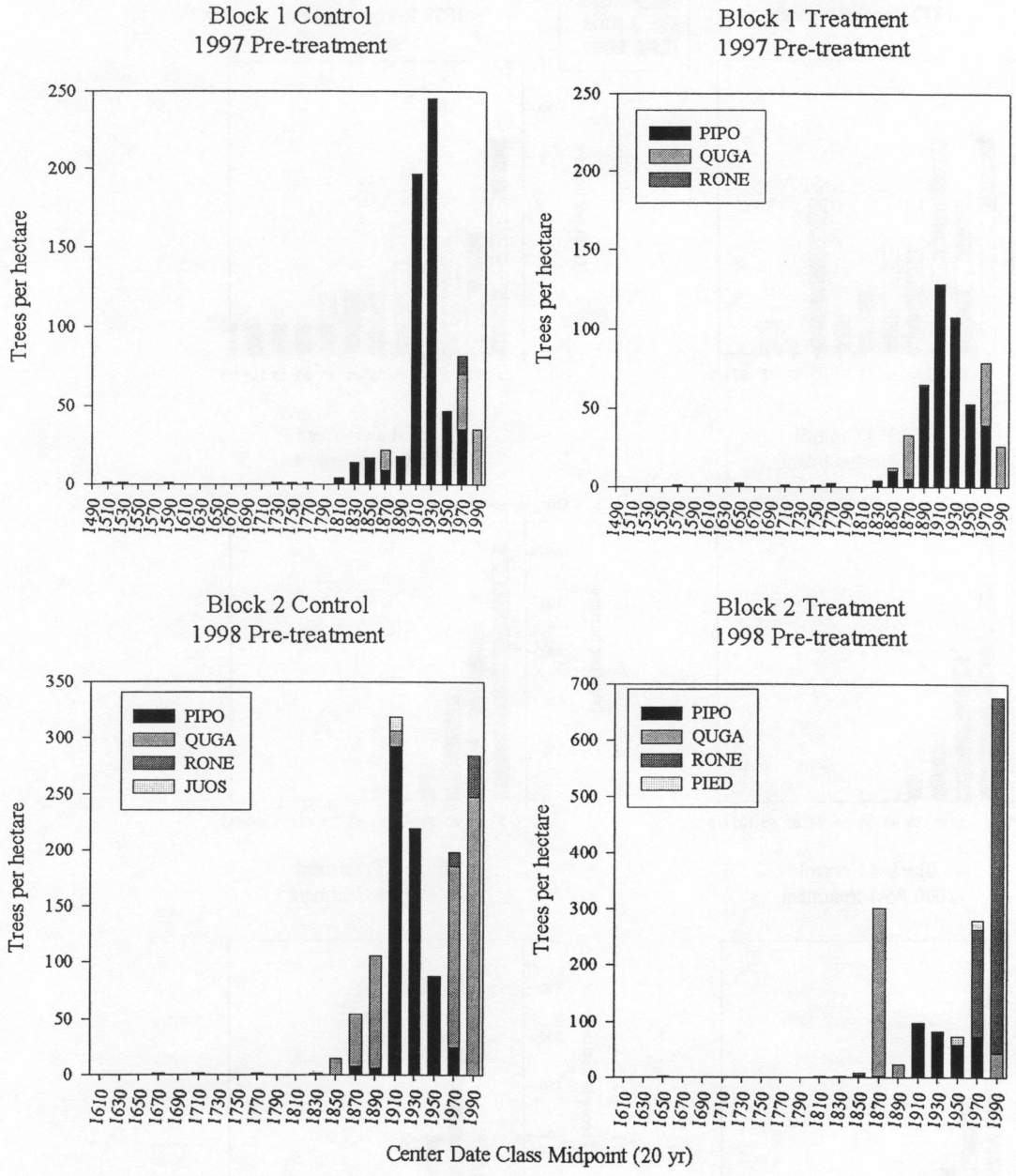

Block 1 Control
1997 Pre-treatment
Block 1 Treatment
1997 Pre-treatment
Block 2 Control
1998 Pre-treatment
Block 2 Treatment
1998 Pre-treatment
Trees per hectare
PIPO
QUGA
RONE
JUOS
PIED
Center Date Class Midpoint (20 yr)

Figure 1.2, continued

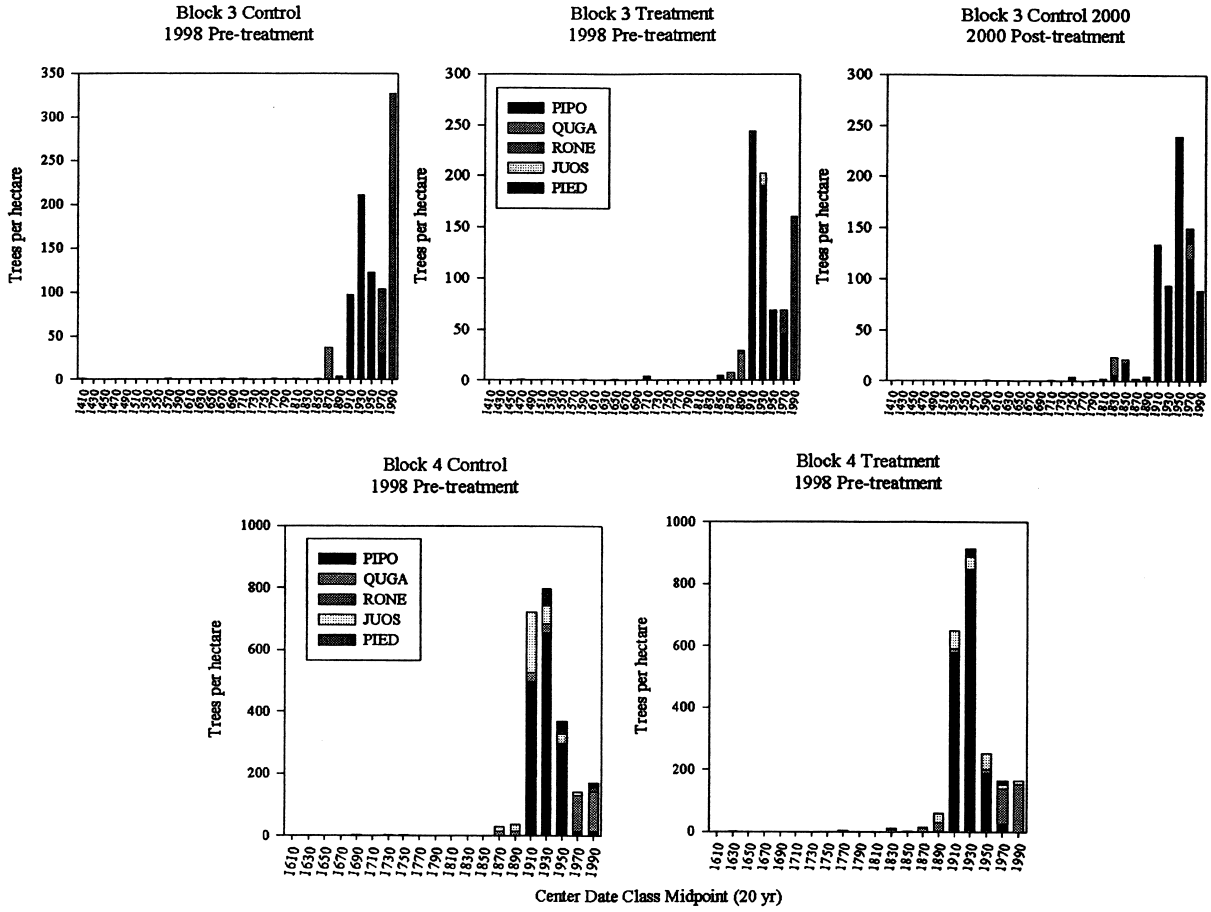


Figure 1.3

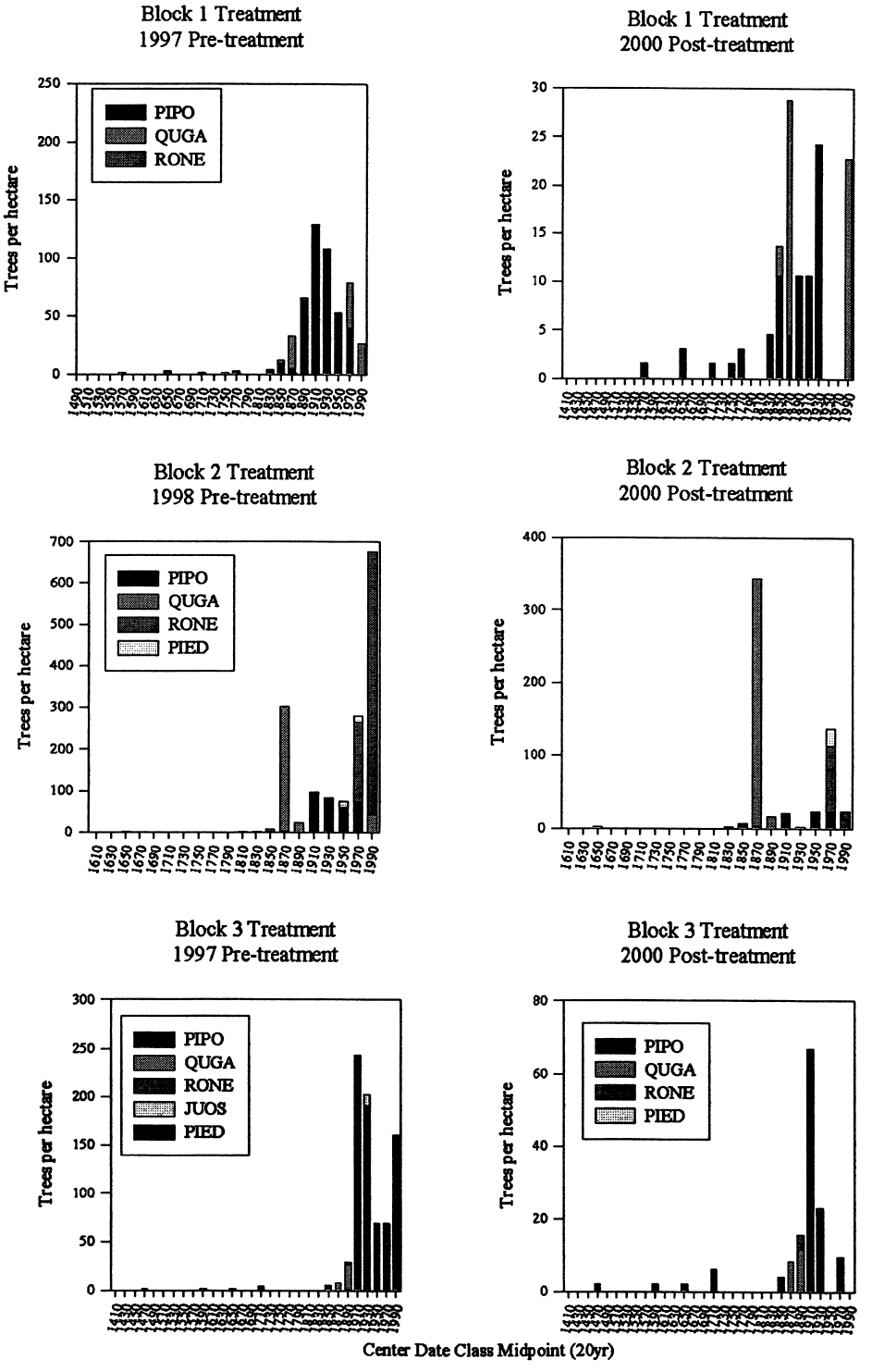

Block 1 Treatment
1997 Pre-treatment
Block 1 Treatment
2000 Post-treatment
Block 2 Treatment
1998 Pre-treatment
Block 2 Treatment
2000 Post-treatment
Block 3 Treatment
1997 Pre-treatment
Block 3 Treatment
2000 Post-treatment
PIPO
QUGA
RONE
JUOS
PIED
Trees per hectare
Center Date Class Midpoint (20yr)

Figure 1.3, continued

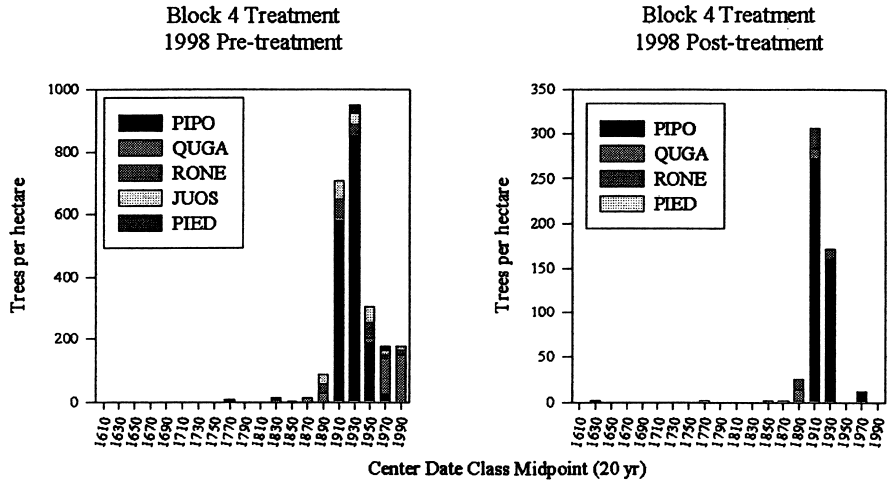


Figure 1.4. Ponderosa pine regeneration in control and treatment units prior to and after restoration treatments.

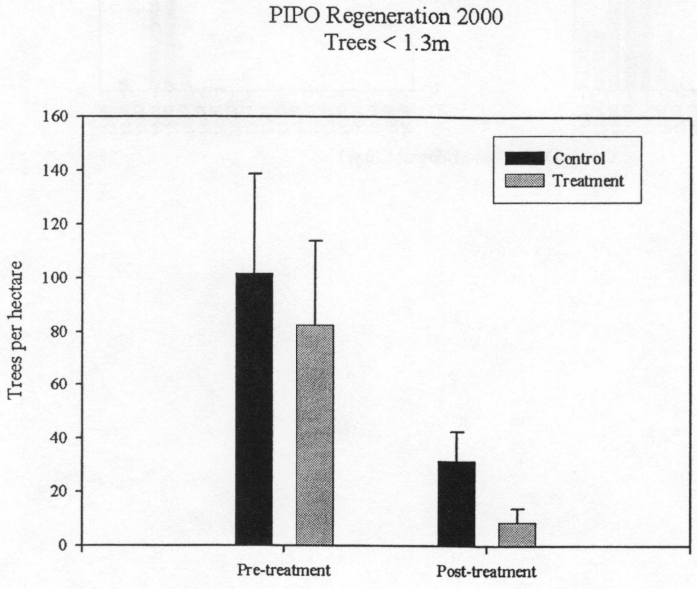
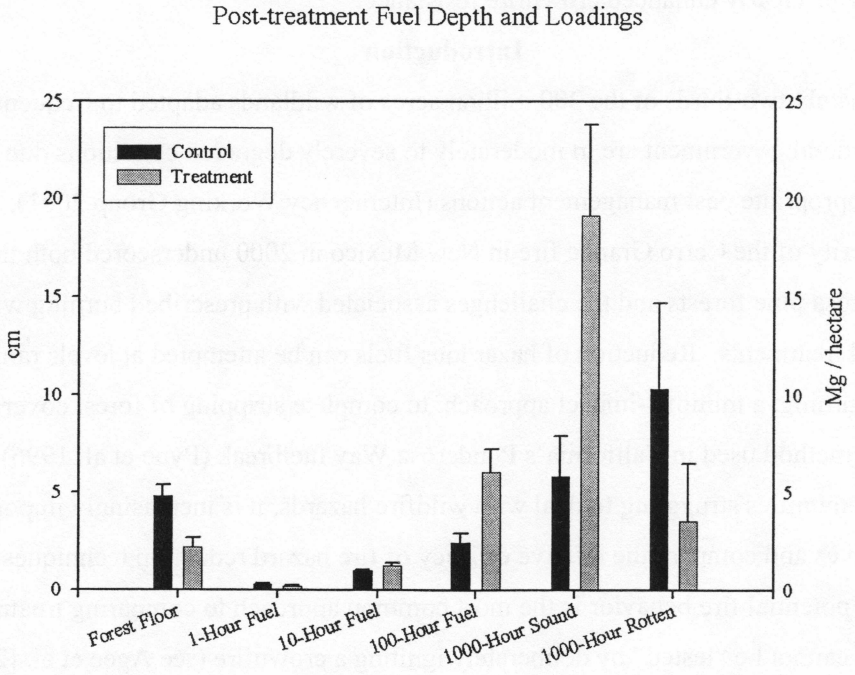


Figure 1.5 Forest fuel loadings following restoration treatment in restored and control forests (n = 4).



Chapter 2: Measuring Forest Restoration Effectiveness in Hazardous Fuels Reduction

Abstract

Forest restoration treatments of thinning young trees followed by prescribed burning in northwestern Arizona led to significantly lower stand density and crown fuel load, and higher crown base height, than untreated stands. Simulated fire under extreme weather conditions caused 48% more canopy burning and higher flame lengths, heat/area, and rate of spread in untreated stands. Windspeeds required for passive crownfire (torching) were twice as high in treated stands. Treated stands were highly heterogeneous but restoration treatments clearly enhanced crownfire resistance.

Introduction

Approximately two-thirds of the 200 million acres of wildlands adapted to frequent fire regimes managed by the federal government are in moderately to severely degraded conditions due to fire exclusion and inappropriate past management actions (Interagency Working Group 2001). The extraordinary severity of the Cerro Grande fire in New Mexico in 2000 underscored both the scale of the problem in ponderosa pine forests and the challenges associated with prescribed burning without benefit of mechanical fuel treatments. Reduction of hazardous fuels can be attempted at levels ranging from prescribed underburning, a minimal-impact approach, to complete stripping of forest cover, the maximum-impact method used in California's Ponderosa Way fuelbreak (Pyne et al. 1996). For resource managers and communities struggling to deal with wildfire hazards, it is increasingly important to test treatment alternatives and compare the relative efficacy of fire hazard reduction techniques.

Modeling potential fire behavior is the most common approach to comparing treatments, since most treated areas cannot be "tested" by deliberately igniting a crownfire (see Agee et al. [2000] for an unplanned test—and failure—of a fuelbreak). Models of crownfire behavior are complex and poorly understood (Scott 1998), but they are important for assessing the potential behavior of high-intensity crownfires with high resistance to control. For example, Kalabokidis and Omi (1998) thinned lodgepole pine plots in Colorado, applied standard models to predict surface fire behavior, and inferred crownfire impacts using nomograms (Rothermel 1991). Scott (1998) integrated surface and crownfire algorithms to develop a stand-scale modeling approach for testing alternative thinning and burning treatments in a Montana ponderosa pine forest. At the landscape scale, Stephens (1998) used the Farsite model as an assessment tool for contrasting treatments.

Restorative management approaches offer the prospect of improvement in ecological parameters such as productivity and diversity, while simultaneously reducing fuel hazards and fire severity (Covington et al. 1997). Many ecosystems adapted to frequent fire, such as ponderosa and related long-

needled western pines, exhibit hazardous fuel accumulations and severe wildfires as the symptoms of ecological imbalances (Wagner et al. 2000). Although experiments initiated by Scott (1998), Lynch et al. (2000), Moore et al. (1999), and others are beginning to provide information on ecological responses, these studies are in early post-treatment phases. Many variables are likely to fluctuate widely in the first years after treatment because rapid successional changes are altering plant and animal communities. Potential fire behavior, however, is an environmental factor that can be affected by treatment in a short time and have long-term effects.

One of the first replicated stand-level experiments in forest restoration in the Southwest began in 1995 as a collaboration between the BLM Arizona Strip District, the Arizona Game and Fish Department, and the Ecological Restoration Institute of Northern Arizona University. The overall project has a broad scope, testing both landscape- and stand-scale treatments, with researchers investigating a broad array of ecosystem responses. Here we report on the effects of forest restoration on fuel reduction, comparing potential behavior of wildfire modeled under extreme weather conditions to assess differences between treatment and control stands.

Methods

The Mt. Trumbull study site is located in the Uinkaret Mountains on the Arizona Strip, north of the Colorado River (latitude 36°22'N, longitude 113°7'W). Soils are derived from volcanic substrates. Annual precipitation at Mt. Trumbull averaged 19.9 in. (1977 to 1997), mostly occurring in winter and during the summer monsoon (July-September). Vegetation includes ponderosa pine (*Pinus ponderosa*)--Gambel oak (*Quercus gambelii*) forest. Utah juniper (*Juniperus osteosperma*), pinyon (*Pinus edulis*), New Mexican locust (*Robinia neomexicana*) and shrub species are interspersed in the pine-oak forest. As elsewhere in the Southwest, surface fires were frequent (mean fire intervals 5-7 years, P.Z. Fulé and others, unpublished data) prior to European settlement of the region beginning in 1870, when livestock grazing, logging, and fire suppression led to substantial increases in forest density (Moore et al. 1999).

Four experimental blocks were established in 1997, representing the range of elevation and forest structure in the Mt. Trumbull forest. Treatments (restoration and control) were randomly assigned to nominally 20-acre units in each block. Twenty permanent monitoring plots were established in each unit in July-August, 1997 (block 1) and April-July, 1998, (total N = 160 plots). Plots were located on a 196.8-ft grid, corresponding to a measured experimental area of 17.8 ac per treatment unit. Overstory trees taller than breast height (4.5 ft) were measured on a 4,306 ft^2 circular fixed-area plot. Trees below breast height and shrubs were tallied by condition class and by height classes on a nested 1,076 ft^2 subplot. Plant species, substrate, and overstory canopy cover (vertical projection) were recorded every 11.8 in.

along a 164-ft line transect oriented upslope. Dead woody biomass and forest floor depth were measured on a 50 ft planar transect in a random direction from each plot center.

The forest restoration prescription was designed to rapidly emulate historic forest structure, followed by re-introduction of surface fire. All old-growth (predating 1870) trees of all species were retained. Where snags, fallen trees, or stumps evidenced old conifers that had died, three younger trees of the same species within a 30-60 ft radius were selected as replacements (Covington et al. 1997). Fire-susceptible deciduous species, oak and locust, were not thinned. Thinning was carried out by commercial contractors and BLM crews in 1999. Slash was lopped and scattered. Deep duff layers were raked 1-3 ft away from boles of all old-growth trees and snags. Treatment units were burned in the winter of 1999-2000. Plots were remeasured in May-July, 2000.

Weather conditions for fire modeling were based on the 90th and 97th percentiles of low fuel moisture, high winds, and high temperature from 34 years of data on the Kaibab National Forest (Tusayan weather station) using the FireFamily Plus program (Bradshaw and Brittain 1999). Weather values were calculated for the entire fire season (April 23 to October 16) as well as for June, historically the month with the most severe fire weather (Table 1).

Fire behavior was modeled with the Nexus Fire Behavior and Hazard Assessment System (Scott and Reinhardt 1999). Crown fuels were estimated with allometric equations for foliage and fine twigs of ponderosa pine (Fulé et al. in press), Gambel oak (Clary and Tiedemann 1986), and pinyon and juniper (Grier et al. 1992). Crown volume was estimated by the averages of maximum tree height (top of the canopy) and crown base height (bottom of the canopy). Crown bulk density was calculated as crown biomass divided by crown volume. For the purposes of predicting passive crownfire behavior (torching), we used the lowest quintile (20%) of crown base heights in each stand. Stand characteristics and model outputs were compared with multivariate analysis of variance followed by post-hoc univariate comparisons (F test, alpha = 0.05).

Results

There were no significant differences in tree density or basal area between treatment-control pairs prior to thinning and burning. After treatment, restoration stands had significantly lower pine density, lower crown fuel load, and higher crown base height (Table 2). Although crown fuel load in treated stands averaged only half that of control stands (54%), crown bulk density in the treatments averaged 85% of control stands. This counterintuitive result is an artifact of raising crown base height when small trees were thinned, reducing crown volume. For instance, in block 4 the treated stand had a slightly higher crown bulk density than the control despite having half the crown biomass.

Fire model results (Table 3) should be interpreted with caution. The models are highly sensitive to crown base height, windspeed (or wind reduction factor), fuel moisture, and surface fuel model variables (1H fuel loading, herbaceous fuels, surface-area-to-volume ratio, fuel bed depth. The behavior of real fires in these stands would be affected by variability in fuels and weather, roads, meadows, surrounding forest fuels, landscape topography, and suppression activities. The standard fire behavior fuel model 9 was intended to represent long-term surface fuels, not the activity fuels that were actually present immediately after thinning (Figure 1). However, when used to compare the treatment alternatives under a common weather scenario, the analysis provided an excellent basis for assessing relative differences in potential fire behavior.

Fires simulated under the severe weather conditions were fast and hot in all stands but fire behavior was significantly less intense in the treated stands (Table 3). Crownfire behavior includes both passive (torching) and active canopy burning. Crown burning was predicted in all of the control stands, three with passive crownfire consuming 38-68% of the canopy and the fourth with active crownfire and complete canopy consumption. Treated stands were not immune from passive crownfire because small oak and locust trees were not thinned, so the lowest quintile crown base heights remained below 10 ft in three of the four treated stands. The treatment unit in block 2, with the most oak, had the lowest crown base and lowest torching index (minimum windspeed that would support passive crownfire). However, treated stands averaged only 20% canopy burned while controls averaged 68%. High flame lengths (average 11.8 ft) and heat/area values (average 673 BTU/ft^2) were predicted in the treated stands, consistent with torching expected to occur in portions of the units, but flame length and heat/area were significantly higher in controls (average 38.0 ft and 1780 BTU/ft^2).

In contrast to the torching index, crowning index was most closely related to crown bulk density. The two indices were poorly correlated. For example, the treated stand in block 2 had a low crown base height (4.5 ft) so the torching index was correspondingly low (11.2 mph), but block 2 had an intermediate crown bulk density value (0.00260 lb/ft^3) so the crowning index was also intermediate (43.0 mph). The opposite occurred in the treated stand in block 4: the high crown bulk density led to a low crowning index of 22.4 mph, less than the 30 mph modeled winds, but no canopy burning was predicted because the high crown base height (25.2 ft) prevented fire from entering the crowns.

Treatment and control stand characteristics from Mt. Trumbull are compared graphically with other southwestern sites in Figure 2. Other experiments included a restoration treatment at Grand Canyon (Fulé et al. in review), at the Flagstaff (AZ) wildland/urban interface (Fulé et al. in press), and the Forests Forever! treatment designed by the Southwest Forest Alliance (1996), a consortium of environmental activist groups. Stand characteristics were broadly variable but restoration sites at Mt. Trumbull and on

the National Forests clearly grouped toward high crownfire resistance (high crowning index), associated with low crown biomass and basal area. Only the densest of the treated stands—Mt. Trumbull block 4—remained grouped with the controls. Control stands were clustered toward low crownfire resistance and high crown biomass and basal area. The Forests Forever! treatments, intentionally designed as a lower-impact forest restoration approach (SWFA 1996), fell in the middle between control and restoration stands. This outcome implies that the lighter thinning of Forests Forever! provided measurable but minimal improvement in crownfire resistance.

Discussion

Nexus and similar fire behavior models offer a valuable approach for making quantitative comparisons across study sites. These comparisons provide a fair, quantitative basis for managers to evaluate the fire behavior implications of alternative treatments. These comparisons are important information in public discussion over treatments to reduce hazardous fuels.

Forest stands were highly variable in stand characteristics following the site-specific restoration treatments, as shown in Table 2 and Figure 2, reflecting the heterogeneity of natural forest conditions. While conserving the range of structural variability, however, restoration treatments shifted the entire distribution toward significantly more crownfire resistance. Application of restoration treatments across the larger landscape of the Mt. Trumbull highlands would be expected to result in a complex, fine-grained mosaic of forest structural conditions, relatively immune from severe wildfire and relatively safe for prescribed burning or wildland fire use for resource benefits.

Forest restoration is a viable approach for shaded fuelbreaks, area treatments (Agee et al. 2000), and urban interface fuel hazard reduction. The primary advantage of restoration is the ability to simultaneously address fire issues and other broad objectives consistent with the evolutionary environment of the ecosystem. Clewell (2000:217) described the process of ecological restoration as "secur[ing] our future by restocking a dangerously depleted global inventory of natural areas." Such comprehensive goals extend well beyond ameliorating wildfire concerns. If restorative management proves even partially successful in recapturing the native productivity and diversity of degraded ecosystems, fuel hazard reduction may eventually be seen as a useful but incidental benefit.

The particular restoration design used at Mt. Trumbull may not be suitable in all critical fire areas. We retained moderately dense stands still subject to some degree of passive crownfire. Maintenance burning is required to check new reproduction from reoccupying the lower stratum of the stand. Because conifers were retained well in excess of the historic (pre-1870) forest density, due to the 3:1 replacement ratio, future thinning entries or snag creation treatments might be necessary to maintain open forest conditions.

Fire hazard is only one of many variables that enter into ecosystem management decisions. The fuel hazard reduction benefits of forest restoration are apparent as soon as thinning and burning have been completed, but long-term monitoring is necessary to measure responses of plant and animal communities, tree mortality and regeneration, and biogeochemical and disturbance processes (e.g., Oliver and Powers 1998). Continued experimentation and adaptive application of monitoring results are also necessary. Arguably the most beneficial outcome of the Forests Forever! treatment has been the stimulation of inquiry on the part of environmental activists to formulate *and implement* an alternative restoration approach. Engagement and testing of ideas by groups across the spectrum of public land stakeholders may be one of the most effective ways to advance thoughtful management of ecosystems.

Acknowledgements

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Table 1. Fuel moisture, wind, and temperature for the Tusayan weather station (Kaibab National Forest), 1966-1999. The 90th and 97th percentiles are shown for the entire fire season (April 23 to October 16) and for the month of June.

	Fire Season 90th percentile	Fire Season 97th percentile	June 90th percentile	June 97th percentile
1 H moisture (%)	3.3	2.6	2.3	1.7
10 H moisture (%)	4.4	3.4	3.0	3.0
100 H moisture (%)	6.8	6.4	4.5	4.5
Wind speed (mph)	13	16.9	15	19
Temperature (°F)	84.7	84.7	90	90

Table 2. Canopy fuel and stand characteristics. Means indicated with asterisks are significantly different (* $p < .10$, ** $p < .05$).

	Block 1	Block 2	Block 3	Block 4	Mean
			Control		
Crown bulk density (lb/ft^3)	0.00220	0.00335	0.00321	0.00610	0.00372
Average crown base height (ft)	8.6	9.4	5.1	10.0	8.3*
Low quintile crown base ht. (ft)	5.2	5.6	2.9	7.2	5.2
Crown fuel load (ton/acre)	3.61	5.41	3.67	6.86	4.89**
Stand height (ft)	84.0	85.3	57.7	61.7	72.2
Basal area (ft^2/acre)	117.7	155.1	117.6	192.3	145.7
Pine density (trees/ac)	245.5	264.2	248.0	658.4	354.0**
Oak/locust density (trees/ac)	30.4	241.4	48.1	154.4	118.6
Pinyon/juniper density (trees/ac)	0	5.6	2.6	149.3	39.4
			Treatment		
Crown bulk density (lb/ft^3)	0.00156	0.00260	0.00217	0.00643	0.00319
Average crown base height (ft)	16.2	14.3	17.5	34.2	20.6*
Low quintile crown base ht. (ft)	9.9	4.5	10.2	25.2	12.4
Crown fuel load (ton/acre)	2.01	2.65	2.23	3.63	2.63**
Stand height (ft)	75.4	61.0	64.6	60.0	65.3
Basal area (ft^2/acre)	67.8	65.0	74.1	115.0	80.5
Pine density (trees/ac)	36.4	18.7	40.5	186.2	70.5**
Oak/locust density (trees/ac)	14.2	210.0	16.2	11.1	62.9
Pinyon/juniper density (trees/ac)	0	1.5	0	13.7	3.8

Table 3. Fire behavior outputs under the June 97th percentile weather conditions with 30 mph winds and lowest quintile crown base height. Foliar moisture content was held constant at 100%, fire behavior fuel model was 9 (hardwood/long-needled conifer litter), and wind reduction factor was 0.3 for all simulations. Means indicated with asterisks are significantly different (* $p < .10$, ** $p < .05$).

	Block 1	Block 2	Block 3	Block 4	Mean
			Control		
Fire type[A]	Passive	Passive	Passive	Active	--
Crown percent burned	38%	65%	69%	100%	68%*
Rate of spread (ft/min)	81.3	108.9	112.2	143.0	111.5*
Heat/area (BTU/ft^2)	986	1796	1396	2942	1780*
Flame length (ft)	20.0	37.7	30.1	64.3	38.0*
Crown Fire Outputs					
Torching index (mph)	12.9	13.9	6.4	17.9	12.8
Crowning index (mph)	48.2	36.4	36.9	22.4	36.0*
			Treatment		
Fire type[A]	Passive	Passive	Passive	Surface	--
Crown percent burned	11%	49%	18%	0	20%*
Rate of spread (ft/min)	55.1	92.5	61.7	43.6	63.3*
Heat/area (BTU/ft^2)	583	962	644	501	673*
Flame length (ft)	9.5	20.0	11.1	6.9	11.8*
Crown Fire Outputs					
Torching index (mph)	24.1	11.2	24.6	55.9	29.0
Crowning index (mph)	61.6	43.0	48.8	22.4	44.0*

[A] Fire types are (1) surface, (2) passive crownfire or "torching," (3) active crownfire.

Figure Legends

Figure 1. Prescribed burning of a forest restoration experimental unit on the Fort Valley Experimental Forest, Coconino National Forest, near Flagstaff, AZ, May 1, 2001. The stand's attributes of relatively high crown base height, low crown fuels, and diverse structure are associated with high resistance to torching and active crownfire.

Figure 2. Comparison of forest basal and crown biomass with crownfire index (minimal windspeed required to sustain active crownfire) shows that high variability exists in both treated and untreated forests, but restoration treatments lead to higher crownfire resistance. Study sites include the four Mt. Trumbull units described in the text as well as analogous sites on the Kaibab (Grand Canyon) and Coconino (Flagstaff) National Forests. The "Forests Forever!" treatment was developed by the Southwest Forest Alliance and implemented on the Kaibab and Gila National Forests. It was intermediate in stand and fire characteristics.

Figure 1.

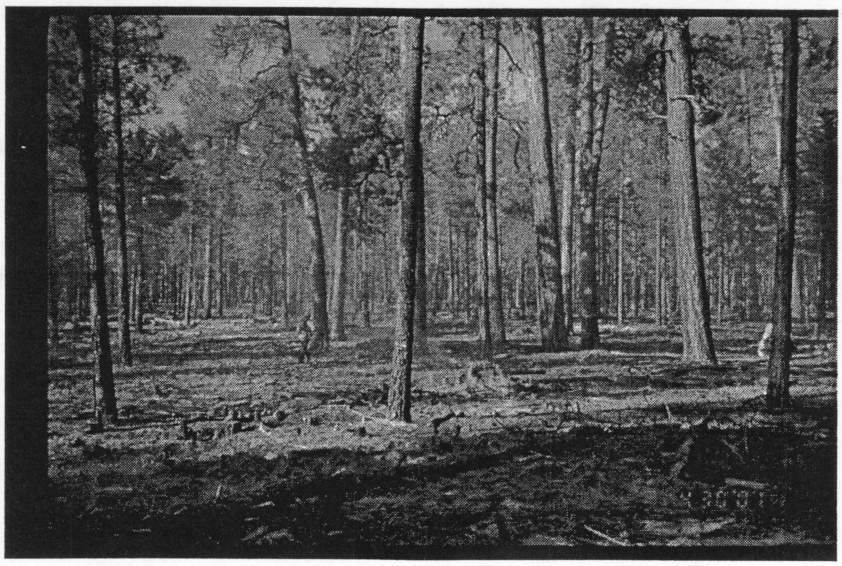
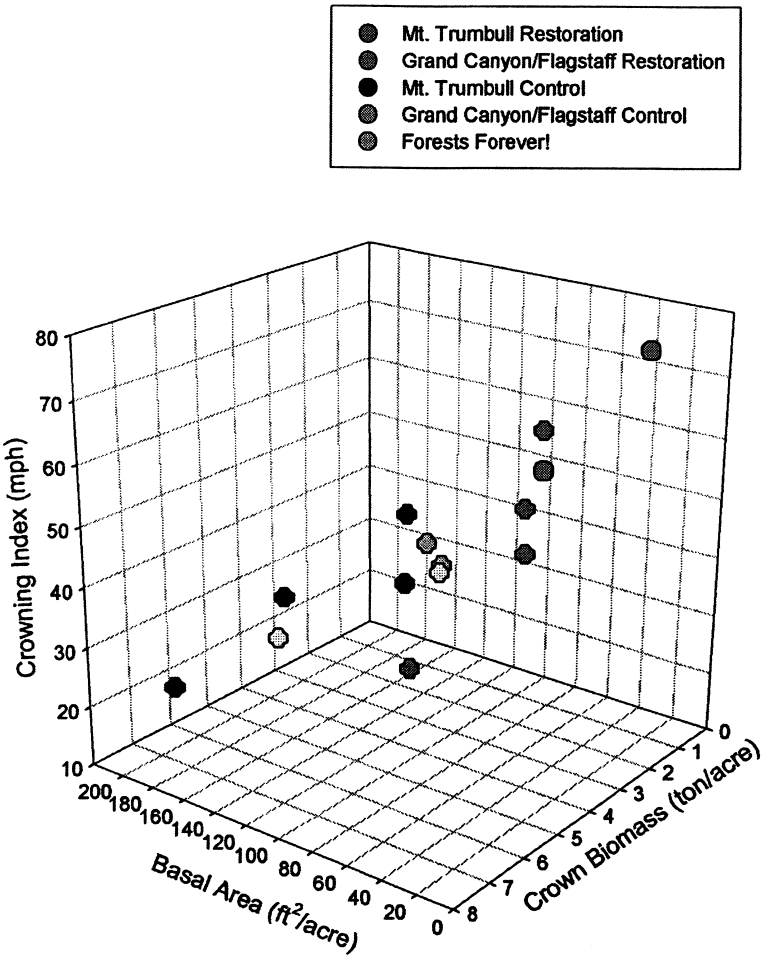


Figure 2.


Mt. Trumbull Restoration
Grand Canyon/Flagstaff Restoration
Mt. Trumbull Control
Grand Canyon/Flagstaff Control
Forests Forever!
Crowning Index (mph)
80
70
60
50
40
30
20
10
Basal Area (ft²/acre)
200 180 160 140 120 100 80 60 40 20 0
Crown Biomass (ton/acre)
0 1 2 3 4 5 6 7 8

Chapter 3

Herbaceous and shrub response to restoration

Introduction: Historic species composition and abundance of understory species is not well-documented or understood in southwestern ponderosa pine forests. We hypothesize that diversity of native shrubs, forbs and grasses (particularly C_4 grasses) has decreased and that overall species diversity has declined, primarily because of increased grazing by domestic and wild ungulates and increasingly closed tree canopies due to fire suppression. Non-native plant species have also increased in number and abundance across the Southwest. Ecological restoration treatments decrease forest floor litter, thus providing mineral soil seedbeds for seed germination. They also open the canopy, which allows increased light levels to reach the forest floor. Decreasing the tree density provides additional available water to understory species.

Several factors occurred to ensure less than adequate conditions for an observable overall positive response to restoration treatments. Because less than 6 months passed since prescribed burning was initiated in the experimental blocks, there was insufficient time to measure an adequate response of the understory. Optimal growing conditions did not occur in 2000 because it was a year of less than average precipitation across much of the Southwest.

Experimental blocks were not seeded, so the observed plant community is a result of natural regeneration, mainly from on-site seed sources (soil seed bank and existing aboveground vegetation) and from off-site dispersal by air, water or animal- and human-mediated dispersal mechanisms.

Methods: Overall methods are outlined in Chapter 1. For herbaceous measurements, we installed one fifty meter transect per plot, from the uphill to the downhill side of the plot. Plants and substrates were recorded every 30 cm along the transect (for a total of 166 points per plot). Presence/absence of species was also tallied within an approximately 10 m wide by 50 m long belt along each transect.

Results: Substrates. Litter levels remained similar following thinning and burning in both the treatment and control units, probably due to high levels prior to burning and to needle scorch and fall following the burn (Figure 3.1). Wood increased in the treatment because of thinning activities and only partial consumption by fire, but increases were also observed in the control. Bare soil cover decreased in both the treatment and control, and rock cover decreased in the control but increased in the treatment. Plant cover decreased significantly for both the treatment and control, probably because of decreased precipitation in 2000. Point line-intercept measurements are fairly subjective and vary based on the size of the measurement device at each point and vary with each field technician. Because of this subjectivity, conclusions should not be made based on fractions of percents or even between a few percentage points.

Species richness. Average species richness per plot remained similar on transects in the control (2.7 pre-treatment and 2.4 post-treatment) (Figure 3.2). However, there was a decrease of approximately 0.3 species per transect in the treated blocks. On the 10 x 50 m belts, approximately 3.5 fewer species were detected per plot in 2000 in the control. However, 0.42 more species were detected in the treatment in 2000. There were significant pre-treatment differences between the number of species on the belts in blocks 1 and 4. The controls both had more species prior to treatment. Following treatments in 2000, significantly more species were detected in the treated units in blocks 1 (12 species in the treatment and 7 in the control) and 2 (approximately 16.5 in the treatment and 7.5 in the control). More species were also tallied in block 3, but these numbers were not significant. However, the treated area in block 4 had significantly fewer species than the control (5 species per plot in the control and 2 species per plot in the treatment).

In other treated sites in southwestern ponderosa pine forest, there are generally decreases in species number the first year following treatments. Because 2000 was a year of low precipitation, species richness is expected to increase following a year or two of favorable moisture at Mt. Trumbull.

Simpson's Diversity Index. Over the entire study area, there were no significant differences in diversity between the treatments and controls (Figure 3.3). However, there were tremendous pre-treatment differences in diversity between the treatment and control in blocks 2 (where the treatment was much higher) and 4 (control was significantly higher). Following treatment, these differences leveled out, but diversity was significantly higher in blocks 3 and 4 in the controls.

Nativity. All plants were categorized based upon their origin as native, introduced, or unknown—plants which either were identifiable only to genus (either because the flowering part essential for a correct identification was not present or because two species hybridized) or for which there is uncertainty in the literature as to their origin. On the Mount Trumbull treatment blocks unknown taxa constituted a very small portion of the plants encountered on both the point line-intercept (0.9%), and the belt transects (2.3%). All of these were classed as unknown because they were identified only to the genus or family level. Due to their low representation, plants of unknown origin were not included in the following nativity analyses.

Post-treatment nativity statistics from the line transects differed from the pre-treatment numbers on all treatment blocks, but not in a uniform direction (Table 3.1). In blocks 1 and 3, introduced species increased in relative frequency from approximately 10 to 21% and 13 to 33%, respectively. In blocks 2 and 4, introduced species relative frequencies decreased after treatment, slightly in block 2, and dramatically in block 4. It should be noted, however, that block 4 shows a large overall decrease in plant cover in the post-treatment measurements, both in the treated and control units, so the decrease of non-

natives is probably unrelated to the treatment. The introduced species that contributed to the above percentages are shown in Table 3.2. *Verbascum thapsus* (common mullein), *Bromus tectorum* (cheatgrass) and *Poa pratensis* (Kentucky bluegrass) account for most of the changes between pre-and post-treatment frequencies. *V. thapsus* and *B. tectorum* increased dramatically on blocks 1 and 3 (respectively), while on block 2 sharp decreases in *B. tectorum* and *P. pratensis* overwhelmed the substantial increase in *V. thapsus* to produce the overall decrease in introduced frequencies seen in Table 3.2. As noted above, plant frequencies decreased across the board in block 4.

Frequencies of non-native species in understory communities at Mt. Trumbull are very high relative to other restoration sites studied by the Ecological Restoration Institute in the ponderosa pine ecosystem. Introduced species accounted for approximately 10% of total cover at Mount Trumbull prior to treatment (and nearly 40% of the plant community) in block 2, whereas treatment blocks on the South Rim of the Grand Canyon at Grandview on average support less than 5% introduced species (with a high of 13.6% on one block), and sites in Fort Valley near Flagstaff generally contain less than 3% (with a high of 12.2%). These numbers suggest that the Mount Trumbull area was more degraded than the other sites by past land management practices prior to restoration treatments (the highest non-native species frequency was found in a pre-treatment measurement), or that the climate or other abiotic factors differ greatly at Mt. Trumbull from these other sites, and that more than just forest thinning and burning may be required to rehabilitate understory communities.

On the belt transects (Table 3.3), a few introduced species were seen to increase after treatment (meaning that they were found on more plots inventoried after treatment). *Verbascum thapsus* and *Bromus tectorum* both increased after treatment in blocks 1, 2 and 3. The increase was sometimes dramatic, as for *V. thapsus* in block 1 (from 5 to 18 plots) and for *B. tectorum* in block 3 (from 2 to 10 plots). *Poa pratensis* also increased in representation after treatment in blocks 1 and 2 (from 0 to 6 and 3 to 6 plots, respectively). This same species, however, decreased after treatment on block 3 (from 1 to 0 plots) and block 4 (from 15 to 4 plots), though again there is an across-the-board decrease in plant representation on block 4, and so results from this block probably do not represent a treatment effect.

Shrubs and Subshrubs. Shrub species found on the Mount Trumbull blocks are numerous, and include *Amelanchier utahensis* (Utah serviceberry), *Arctostaphylos patula* (greenleaf manzanita), *Arctostaphylos pungens* (pointleaf manzanita), *Artemisia tridentata* (big sagebrush), *Ceanothus fendleri* (Fendler's ceanothus), *Ceanothus martinii* (Martin's ceanothus), *Chrysothamnus viscidiflorus* (green rabbitbrush), *Ericameria nauseosa* ssp. *nauseosa* (rubber rabbitbrush), *Fallugia paradoxa* (Apache-plume), *Mahonia fremontii* (Fremont's mahonia), *Purshia mexicana* (Mexican cliffrose), *Purshia tridentata* (antelope bitterbrush), *Quercus turbinella* (shrub live oak), *Rhus trilobata* (skunkbush sumac),

Ribes cereum (wax currant), *Symphoricarpos oreophilus* (whortleleaf snowberry) and *Symphoricarpos oreophilus* var. *utahensis* (Utah snowberry). There was some confusion in the field about the species of *Amelanchier* found in the Mount Trumbull region. Most specimens were identified as *A. utahensis*, but some with new growth in the treated units showed much larger leaves and were identified as *A. alnifolia* (Saskatoon serviceberry). There is debate among specialists as to whether *A. alnifolia* is actually present in Arizona, and for the purposes of this report all the specimens are referred to as *A. utahensis*. Subshrubs are generally shorter than shrubs, but are still woody at least at the base. The only plant identified as a subshrub at the Mount Trumbull sites is *Mahonia repens* (Oregon-grape). In the following analyses *Mahonia repens* will be considered together with the shrubs.

On the point line-intercept transects, there was a general decrease in absolute frequencies of shrub species in the treated units (Table 3.4). This is probably a result of prescribed burning, especially since most of the control units record a slight increase in shrub frequencies during the same period. *Artemisia tridentata* provides a particularly good example of this trend, with the absolute frequency in the treated unit of block 2 decreasing from 6.7 to 3.3% while in the control unit the frequency increased from 0.2 to 0.5%. It is worth noting that the loss of shrubs in both the control and treatment units of block 1 may have more to do with difficulties in relocating the transects than any treatment or weather effects. We expect shrub diversity and abundance to increase over time following restoration treatments, since many of these species take at least a year to germinate or resprout following fire.

Belt transects record a different kind of information about vegetation patterns than do point line-intersect transects. They capture more species than line transects (Table 3.5), and are more likely to mark the presence of small, scattered individuals such as seedlings. In the Mount Trumbull treatment blocks the general decrease in shrub frequencies seen on the line transects is not mirrored in the belt transect data. Instead, several species are seen to increase in the post-treatment data, possibly representing sprouting or recruitment of seedlings after thinning and burning. *Ceanothus fendleri* and *Ribes cereum* both are found on more plots after treatment than before in blocks 1 and 3. However, *Ribes cereum* or *Ribes* sp. actually decreased slightly after treatment in blocks 2 and 4, confounding the apparent trend seen in the other two blocks.

Legumes. Because of their nitrogen-fixing capabilities, species in the Fabaceae (legume) family are important members of the plant community, and their response to restoration treatments may influence the response of other species that depend on the soil nitrogen they provide. The point line-intercept transects captured a relatively small number of legumes (Table 3.6), although the Fabaceae is one of the most common families at Mt. Trumbull, and the minimal changes between pre- and post-treatment measurements do not follow a consistent trend. In blocks 1 and 2, legume species generally

increased across both the control and treated units from 1997/98 to 2000. The data from blocks 3 and 4 is less consistent, but there is a general decrease in legume species in both the control and treated units over the same time period. The lack of uniformity in these data suggest that, at least in the short term, legume species respond individually to treatment effects, depending on site-specific microclimate and other factors.

Grasses. Frequencies of grass species from the point line-intercept transects are shown in Table 3.7. Over the entire study area, only seven grass species were captured by the transects. The most widely-occurring species are both native: *Poa fendleriana* (muttongrass) and *Elymus elymyoides* ssp. *elymoides* (squirreltail). However, *Bromus tectorum* (cheatgrass) and *Poa pratensis* (Kentucky bluegrass), both non-native species, make up a significant portion of the plant community. No consistent trends are apparent in the differences between pre- and post-treatment measurements, either in the control or treated units.

Families. Plants found on point line-intercept transects in the Mount Trumbull treatment blocks were grouped according to family affiliation, and listed in Table 3.8 by block. The Poaceae (grass) and Fabaceae (legume) families are generally the most common throughout the study area (both pre- and post-treatment), though in certain blocks the Cyperaceae (sedges), Scrophulariaceae (snapdragon family) and Lamiaceae (mint family) are also well-represented. A given plant family may contain many species with widely different ecological tolerances, so a comparison of pre- and post-treatment family frequencies does not necessarily tell us much about effects of thinning and burning treatments on understory vegetation. Indeed, over all there is little change between the pre- and post-data. One noticeable change, though, is seen in the treated unit of block 4, where 75% of the plant families found in the pre-treatment measurements were not found in the post-treatment measurements. A smaller drop in family diversity was recorded in the control unit as well, though, so this decrease does not necessarily represent a treatment effect.

Special Status Species. The only special status species recorded in the experimental blocks was *Galium bifolium* (G5, S1) (Arizona Game & Fish 1998). It occurred pre-treatment on one plot in block 2 (3 occurrences on the transect), but was not recorded after treatment. It was listed on this same plot on the belt pre-treatment, but was not recorded post-treatment. With this limited amount of data, it is not possible to determine whether its absence post-treatment is due to a treatment effect or to some other factor, such as climate or herbivory.

Community Data. Non-metric multidimensional scaling ordinations (NMDS) were performed on the community data (Figures 3.4 and 3.5) to demonstrate how similar the communities in the various blocks are to each other. The pre-treatment belt data indicates that the treatment and control communities in each block are more similar to each other than to the other blocks (Figure 3.4). However, blocks 2 and

4 are more similar to each other than to the other blocks, and blocks 1 and 3 are more similar to each other. Soils data supports this pattern. Block 1 is situated on a relatively recent lava flow, while block 3 is located on a cinder cone, with fairly coarse soils. Blocks 2 and 4 are located on fine-grained vesicular basalt soils. Post-treatment patterns remained fairly similar to the pre-treatment patterns (Figure 3.5). However, block 3 is beginning to diverge somewhat, and the control is becoming more similar to block 1, while the treatment is becoming more like block 2.

Discussion. Because this report encompasses only data collected less than one year after ecological restoration treatments, and there are few to no apparent trends yet, very few conclusions can be drawn. However, one area of concern is the high number of non-native species in the plant community at Mt. Trumbull. Common mullein should eventually be limited to the belowground plant community, in the form of viable seeds in the seed bank. However, cheatgrass invasion of areas undergoing restoration deserves some attention. Another area of concern is dispersal ability of native plants into the restored areas, and whether there will be enough propagules to colonize these areas to be able to compete with non-native species. As more data are collected from the experimental blocks, community trends should become more apparent with time.

Table 3.1. Percent nativity of plant species found on point line-intercept transects on Mt. Trumbull EB plots, by treatment (I=introduced, N=native). Note: frequencies for the block 3 control in 1997-98 refer to the old control unit (later burned in wildfire), while measurements for 2000 come from the new control unit.

		Absolute Freq. (%)		Relative Freq. (%)	
Unit	**Nativity**	**1997-98**	**2000**	**1997-98**	**2000**
Block 1					
Control	I	0.12	0	10.8	0
	N	0.99	0.82	89.2	100
Treatment	I	0.18	0.48	9.8	21.3
	N	1.66	1.78	90.2	78.7
Block 2					
Control	I	0.15	0.13	2.6	1.8
	N	5.63	6.98	97.4	98.2
Treatment	I	12.35	10	40.2	36.4
	N	18.37	17.44	59.8	63.6
Block 3					
Control	I	0	0.03	0	1.6
	N	3.55	1.84	100	98.4
Treatment	I	0.42	1.17	12.5	33.3
	N	2.95	2.35	87.5	66.7
Block 4					
Control	I	0.96	0	32.3	0
	N	2.02	1.45	67.7	100
Treatment	I	0.15	0	8.8	0
	N	1.57	0.06	91.2	100

Table 3.2. Introduced species frequencies from point line-intercept transects at Mount Trumbull. Species with an asterisk (*) are listed as noxious weeds in the state of Arizona. Note: frequencies for the block 3 control in 1997-98 refer to the old control unit (later burned in wildfire), while measurements for 2000 come from the new control unit.

Unit	Species	Absolute Freq. (%)		Relative Freq. (%)	
		1997-98	2000	1997-98	2000
Block 1					
Control	*Verbascum thapsus*	0.12	0	100	0
Treatment	*Bromus tectorum*	0.15	0	83.3	0
	Poa pratensis	0	0.06	0	12.5
	Verbascum thapsus	0.03	0.42	16.7	87.5
Block 2					
Control	*Bromus tectorum*	0.15	0.13	100	100
Treatment	*Bromus tectorum*	10.81	8.67	87.6	86.7
	Leonurus cardiaca	0.06	0.03	0.5	0.3
	Poa pratensis	1.36	0.66	11.0	6.6
	Polygonum convolvulus	0	0.03	0	0.3
	Taraxacum officinale	0	0.06	0	0.6
	Tragopogon dubius	0.03	0.15	0.2	1.5
	Verbascum thapsus	0.09	0.39	0.7	3.9
Block 3					
Control	*Verbascum thapsus*	0	0.03	0	100
Treatment	*Bromus tectorum*	0	1.05	0	89.7
	*Convolvulus arvensis**	0.09	0	21.4	0
	Lappula occidentalis var. *occidentalis*	0.09	0	21.4	0
	Leonurus cardiaca	0.06	0	14.3	0
	Verbascum thapsus	0.18	0.12	42.9	10.3
Block 4					
Control	*Poa pratensis*	0.96	0	100	0
Treatment	*Poa pratensis*	0.15	0	100	0

Table 3.3. Introduced species occurrence on belt transects at the Mt. Trumbull EB plots, with the number of transects each was found on (out of 20 per unit). Species with an asterisk (*) are listed as noxious weeds in the state of Arizona. Note: frequencies for the block 3 control in 1997-98 refer to the old control unit (later burned in wildfire), while measurements for 2000 come from the new control unit.

Unit	Species	1997-98	2000	Unit	Species	1997-98	2000
Block 1				**Block 1**			
Control	*Bromus inermis*	0	1	**Treatment**	*Bromus inermis*	1	0
	Bromus tectorum	2	0		*Bromus tectorum*	0	2
	Poa pratensis	1	0		*Poa pratensis*	0	6
	Taraxacum officinale	1	0		*Verbascum thapsus*	5	18
	Thinopyrum intermedium	0	1				
	Verbascum thapsus	5	4				
Block 2				**Block 2**			
Control	*Bromus tectorum*	4	5	**Treatment**	*Bromus tectorum*	17	19
	Medicago sativa	0	1		*Lactuca serriola*	0	1
	Verbascum thapsus	2	3		*Leonurus cardiaca*	3	2
					Marrubium vulgare	0	1
					Poa pratensis	3	6
					Polygonum convolvulus	6	5
					Taraxacum officinale	3	4
					Tragopogon dubius	7	10
					Verbascum thapsus	11	13
Block 3				**Block 3**			
Control	*Bromus tectorum*	1	3	**Treatment**	*Bromus tectorum*	2	10
	Poa pratensis	0	1		*Convolvulus arvensis**	1	0
	Verbascum thapsus	5	13		*Lactuca serriola*	0	1
	Tragopogon dubius	1	0		*Leonurus cardiaca*	1	4
					Marrubium vulgare	0	2
					Poa pratensis	1	0
					Polygonum convolvulus	0	4
					Verbascum thapsus	4	8
Block 4				**Block 4**			
Control	*Bromus tectorum*	1	0	**Treatment**	*Poa pratensis*	15	4
	Poa pratensis	15	2				
	Taraxacum officinale	1	0				
	Verbascum thapsus	2	0				

Table 3.4. Frequencies of shrub species found on point-line intercept transects from the Mt. Trumbull EB plots. Note: frequencies for the block 3 control in 1997-98 refer to the old control unit (later burned in wildfire), while measurements for 2000 come from the new control unit.

		Absolute Freq. (%)		Relative Freq. (%)	
Unit	**Species**	**1997-98**	**2000**	**1997-98**	**2000**
Block 1					
Control	*Amelanchier utahensis*	1.2	0.73	61.9	64.9
	Artemisia tridentata	0.1	0.2	3.2	16.2
	Ceanothus fendleri	0.2	0.1	12.7	8.1
	Purshia tridentata	0.1	0	3.2	0
	Rhus trilobata	0.1	0	6.3	0
	Ribes cereum	0.2	0.1	12.7	10.8
Treatment	*Amelanchier utahensis*	1.7	1.6	28.5	38.8
	Arctostaphylos pungens	0.0	0	0.5	0
	Artemisia tridentata	0.8	0.7	13.2	15.8
	Ceanothus fendleri	1.3	0.3	22.2	6.5
	Ceanothus martinii	0.03	0	0.5	0
	Rhus trilobata	0.03	0	0.5	0
	Ribes cereum	2.0	1.6	34.4	38.8
Block 2					
Control	*Amelanchier utahensis*	0	0.1	0	10.5
	Artemisia tridentata	0.2	0.5	100	89.5
Treatment	*Artemisia tridentata*	6.7	3.3	100	100
Block 3					
Control	*Amelanchier utahensis*	0	1.0	0	11.1
	Artemisia tridentata	3.6	6.9	100	79.4
	Ceanothus martinii	0	0.7	0	8.4
	Purshia tridentata	0	0.03	0	0.3
	Ribes cereum	0	0.1	0	0.7
Treatment	*Artemisia tridentata*	2.0	0.2	100	100
Block 4					
Control	*Amelanchier utahensis*	0.27	0.51	100	81
	Symphoricarpos oreophilus	0.00	0.12	0	19
Treatment	*Amelanchier utahensis*	0.15	0.03	83.3	100
	Artemisia tridentata	0.03	0.00	16.7	0

Table 3.5. Shrub species found on belt transects from the Mt. Trumbull EB plots, with the number of transects each species was encountered on (out of 20 per unit). Asterisks (*) indicate species which were found on the belts but not the point line-intercept transects. Note: frequencies for the block 3 control in 1997-98 refer to the old control unit (later burned in wildfire), while measurements for 2000 come from the new control unit.

		1997-98				1997-98	
Unit	**Species**		**2000**	**Unit**	**Species**		**2000**
Block 1				**Block 1**			
Control	*Amelanchier utahensis*	17	13	**Treatment**	*Amelanchier utahensis*	12	16
	Artemisia tridentata	6	4		*Arctostaphylos patula**	0	1
	Ceanothus fendleri	6	6		*Artemisia tridentata*	5	11
	*Fallugia paradoxa**	2	0		*Ceanothus fendleri*	6	13
	*Purshia mexicana**	1	0		*Fallugia paradoxa**	0	1
	Purshia tridentata	7	4		*Purshia mexicana**	3	0
	Rhus trilobata	10	3		*Purshia tridentata**	4	2
	Ribes cereum	14	11		*Rhus trilobata*	5	3
	Sambucus nigra ssp. *cerulea**	3	1		*Ribes cereum*	7	19
Block 2				**Block 2**			
Control	*Amelanchier utahensis*	2	2	**Treatment**	*Amelanchier utahensis**	4	0
	Artemisia tridentata	10	6		*Artemisia tridentata*	15	13
	*Mahonia repens**	9	9		*Mahonia repens**	1	0
					*Ribes cereum**	3	1
					Ribes sp.*	2	0
					Symphoricarpos oreophilus var. *utahensis**	1	0
Block 3				**Block 3**			
Control	*Amelanchier utahensis*	1	19	**Treatment**	*Artemisia tridentata*	9	8
	*Arctostaphylos pungens**	0	1		*Ceanothus fendleri**	0	3
	Artemisia tridentata	19	17		*Mahonia repens**	0	1
	Ceanothus fendleri	2	0		*Ribes cereum**	0	1
	Ericameria nauseosa ssp. *nauseosa* var. *nauseosa**	0	1		*Symphoricarpos oreophilus* var. *utahensis**	1	0
	Ceanothus martinii	0	12				
	Chrysothamnus viscidiflorus	4	0				
	*Rhus trilobata**	0	3				
	Ribes cereum	1	8				
Block 4				**Block 4**			
Control	*Amelanchier utahensis*	18	17	**Treatment**	*Amelanchier utahensis*	16	10
	*Mahonia repens**	7	8		*Artemisia tridentata*	1	1
	*Purshia mexicana**	0	1		*Mahonia fremontii**	1	1
	*Ribes cereum**	2	2		*Mahonia repens**	2	1
	Symphoricarpos oreophilus	3	8		*Ribes* sp.*	1	0
	Symphoricarpos oreophilus var. *utahensis*	4	0		*Symphoricarpos oreophilus**	5	0

Table 3.6. Frequencies of legumes from point line-intercept transects at Mount Trumbull. Note: frequencies for the block 3 control in 1997-98 refer to the old control unit (later burned in wildfire), while measurements for 2000 come from the new control unit.

		Absolute Freq. (%)		Relative Freq. (%)	
Unit	**Species**	**1997-98**	**2000**	**1997-98**	**2000**
Block 1					
Control	*Robinia neomexicana*	0.03	0.09	100	100
Block 2					
Control	*Astragalus argophyllus*	0.03	0	2.3	0
	Lupinus argenteus	1.20	1.97	90.9	87.3
	Robinia neomexicana	0.09	0.29	6.8	12.7
Treatment	*Lotus wrightii*	0.09	0	1.1	0
	Lupinus argenteus	6.45	7.41	81.4	83.4
	Robinia neomexicana	1.39	1.48	17.5	16.6
Block 3					
Control	*Lotus plebeius*	0	0.06	0	4.3
	Lotus wrightii	0.03	0	0.6	0
	Lupinus argenteus	0.15	0.03	2.8	2.1
	Robinia neomexicana	5.09	1.33	96.6	93.6
Treatment	*Lotus wrightii*	0.06	0	2	0
	Lupinus argenteus	0.90	0.69	29.4	37.7
	Robinia neomexicana	2.11	1.14	68.6	62.3
Block 4					
Control	*Lathyrus laetivirens*	0.12	0	100	0
	Robinia neomexicana	0	0.03	0	50
	Vicia americana	0	0.03	0	50
Treatment	*Lupinus kingii*	0.03	0	20	0
	Robinia neomexicana	0.12	0	80	0

Table 3.7. Grass frequencies from point line-intercept transects at Mount Trumbull. An asterisk (*) after a species indicates that it is a C4 grass. Note: frequencies for the block 3 control in 1997-98 refer to the old control unit (later burned in wildfire), while measurements for 2000 come from the new control unit.

		Absolute Freq. (%)		Relative Freq. (%)	
Unit	**Species**	**1997-98**	**2000**	**1997-98**	**2000**
Block 1					
Control	*Elymus elymoides* ssp. *elymoides*	0.09	0.09	20	28.6
	Poa fendleriana	0.36	0.22	80	71.4
Treatment	*Bromus tectorum*	0.15	0	20.8	0
	Elymus elymoides ssp. *elymoides*	0.09	0.12	12.5	28.6
	Poa fendleriana	0.48	0.24	66.7	57.1
	Poa pratensis	0	0.06	0	14.3
Block 2					
Control	*Bouteloua gracilis**	0.03	0.03	1.1	0.8
	Bromus tectorum	0.15	0.13	5.3	3.1
	Elymus elymoides ssp. *elymoides*	2.56	3.96	89.5	96.2
	Poa fendleriana	0.12	0	4.2	0
Treatment	*Bromus tectorum*	10.81	8.67	56.7	57.5
	Elymus elymoides ssp. *elymoides*	6.87	5.75	36	38.1
	Poa fendleriana	0.03	0	0.2	0
	Poa pratensis	1.36	0.66	7.1	4.4
Block 3					
Control	*Bouteloua gracilis**	0	0.30	0	30.3
	Elymus elymoides ssp. *elymoides*	2.09	0.60	63.5	60.6
	Elymus trachycaulus ssp. *trachycaulus*	1.17	0	35.6	0
	Poa fendleriana	0.03	0.09	0.9	9.1
Treatment	*Bromus tectorum*	0	1.05	0	64.8
	Elymus elymoides ssp. *elymoides*	0.99	0.57	80.5	35.2
	Elymus trachycaulus ssp. *trachycaulus*	0.18	0	14.6	0
	Poa fendleriana	0.06	0	4.9	0
Block 4					
Control	*Bouteloua gracilis**	0.03	0	1.9	0
	Elymus elymoides ssp. *elymoides*	0.30	0.24	18.9	29.6
	Poa fendleriana	0.30	0.57	18.9	70.4
	Poa pratensis	0.96	0	60.4	0
Treatment	*Bouteloua gracilis**	0.06	0	11.8	0
	Poa fendleriana	0.27	0	52.9	0
	Poa pratensis	0.15	0	29.4	0
	*Schizachyrium scoparium**	0.03	0	5.9	0

Table 3.8. Frequencies of families found on point line-intercept transects on the Mt. Trumbull EB plots.

Unit	Family	Abs. Frequencies (%) 1997-8	Abs. Frequencies (%) 2000	Rel. Frequencies (%) 1997-8	Rel. Frequencies (%) 2000
Block 1					
Control	Asclepiadaceae	0	0.09	0	10.5
	Asteraceae	0.12	0	10.8	0
	Brassicaceae	0	0.04	0	5.3
	Cyperaceae	0.12	0.26	10.8	31.6
	Euphorbiaceae	0.03	0	2.7	0
	Lamiaceae	0.15	0	13.5	0
	Poaceae	0.45	0.3	40.5	36.8
	Polemoniaceae	0.03	0	2.7	0
	Scrophulariaceae	0.21	0.13	18.9	15.8
Block 2					
Control	Asteraceae	0.15	0.1	2.6	1.3
	Berberidaceae	0.21	0.29	3.6	4
	Cyperaceae	0.21	0.38	3.6	5.4
	Fabaceae	1.23	1.97	20.9	27.7
	Liliaceae	0.18	0	3.1	0
	Onagraceae	0.27	0	4.6	0
	Poaceae	2.86	4.12	48.5	58
	Polemoniaceae	0.27	0.1	4.6	1.3
	Polygonaceae	0.15	0.03	2.6	0.5
	Ranunculaceae	0.03	0.03	0.5	0.5
	Scrophulariaceae	0.3	0.1	5.1	1.3
	Violaceae	0.03	0	0.5	0

Unit	Family	Abs. Frequencies (%) 1997-8	Abs. Frequencies (%) 2000	Rel. Frequencies (%) 1997-8	Rel. Frequencies (%) 2000
Block 1					
Treatment	Asclepiadaceae	0.03	0.09	1.6	4
	Asteraceae	0.06	0.03	3.2	1.3
	Brassicaceae	0.03	0.03	1.6	1.3
	Cyperaceae	0.21	0.36	11.3	16
	Fumiariaceae	0	0.12	0	5.3
	Lamiaceae	0.54	0.6	29	26.7
	Onagraceae	0	0.15	0	6.7
	Poaceae	0.72	0.42	38.7	18.7
	Scrophulariaceae	0.27	0.45	14.5	20
Block 2					
Treatment	Asteraceae	0.75	0.42	2.4	1.5
	Berberidaceae	0.06	0	0.2	0
	Brassicaceae	0.03	0	0.1	0
	Chenopodiaceae	0.06	1.33	0.2	4.8
	Convolvulaceae	0	0.03	0	0.1
	Cyperaceae	0.24	0.09	0.8	0.3
	Euphorbiaceae	0.24	0.36	0.8	1.3
	Fabaceae	6.54	7.41	21.1	27
	Lamiaceae	0.63	0.12	2	0.4
	Liliaceae	0.09	0	0.3	0
	Loasaceae	0	0.06	0	0.2
	Nyctaginaceae	0	0.03	0	0.1
	Onagraceae	0.03	0.09	0.1	0.3
	Poaceae	19.07	15.09	61.6	55
	Polemoniaceae	0.81	0.63	2.6	2.3

Unit	Family	Abs. Frequencies (%) 1997-8	Abs. Frequencies (%) 2000	Rel. Frequencies (%) 1997-8	Rel. Frequencies (%) 2000
Block 3					
Control	Asteraceae	0.09	0.15	2.5	8.1
	Euphorbiaceae	0.09	0.27	2.5	14.5
	Fabaceae	0.18	0.09	5.1	4.8
	Gentianaceae	0	0.12	0	6.5
	Onagraceae	0.03	0.03	0.8	1.6
	Poaceae	3.13	0.99	88.2	53.2
	Polygonaceae	0.03	0	0.8	0
	Ranunculaceae	0	0.03	0	1.6
	Scrophulariaceae	0	0.18	0	9.7
Block 4					
Control	Berberidaceae	0.06	0.06	2	4.2
	Chenopodiaceae	0.03	0	1	0
	Cyperaceae	0.72	0.42	24.2	29.2
	Fabaceae	0.12	0.03	4	2.1
	Onagraceae	0.06	0	2	0
Block 2					
Treatment	Polygonaceae	0.21	0.15	0.7	0.5
	Ranunculaceae	0.03	0	0.1	0
	Rubiaceae	0.09	0	0.3	0
	Scrophulariaceae	1.14	1.02	3.7	3.7
	Solanaceae	0	0.03	0	0.1
	Violaceae	0.93	0.57	3	2.1
Block 3					
Treatment	Asteraceae	0.09	0	2.3	0
	Boraginaceae	0.09	0	2.3	0
	Caryophyllaceae	0.03	0	0.8	0
	Chenopodiaceae	0	0.6	0	17.1
	Convolvulaceae	0.09	0	2.3	0
	Euphorbiaceae	0.09	0.03	2.3	0.9
	Fabaceae	0.96	0.69	25	19.7
	Lamiaceae	0.09	0	2.3	0
	Onagraceae	0.12	0.03	3.1	0.9
	Poaceae	1.23	1.63	32	46.2
	Polemoniaceae	0	0.18	0	5.1
	Polygonaceae	0.48	0.03	12.5	0.9
	Scrophulariaceae	0.45	0.3	11.7	8.5
	Solanaceae	0.12	0	3.1	0
	Verbenaceae	0	0.03	0	0.9
Block 4					
Treatment	Asteraceae	0.03	0	1.7	0
	Cyperaceae	0.24	0.03	13.3	50
	Fabaceae	0.03	0	1.7	0
	Onagraceae	0.33	0	18.3	0
	Poaceae	0.51	0	28.3	0

Unit	Family	Abs. Frequencies (%) 1997-8	Abs. Frequencies (%) 2000	Rel. Frequencies (%) 1997-8	Rel. Frequencies (%) 2000	Unit	Family	Abs. Frequencies (%) 1997-8	Abs. Frequencies (%) 2000	Rel. Frequencies (%) 1997-8	Rel. Frequencies (%) 2000
Block 4						**Block 4**					
Control	Poaceae	1.6	0.81	53.5	56.3	**Treatment**	Polemoniaceae	0.06	0.03	3.3	50
	Polemoniaceae	0.21	0.03	7.1	2.1		Polygonaceae	0.09	0	5	0
	Polygonaceae	0.06	0	2	0		Scrophulariaceae	0.51	0	28.3	0
	Scrophulariaceae	0.12	0.09	4	6.3						

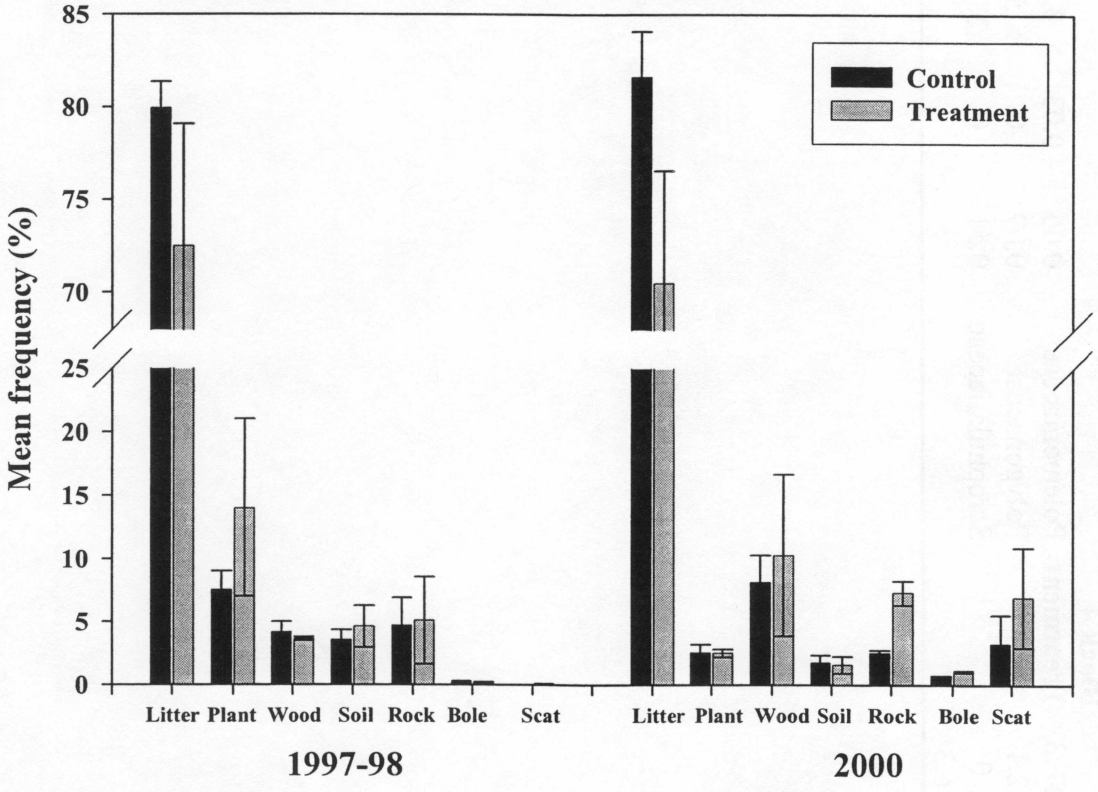


Figure 3.1. Substrate frequencies in four experimental blocks at Mt. Trumbull.

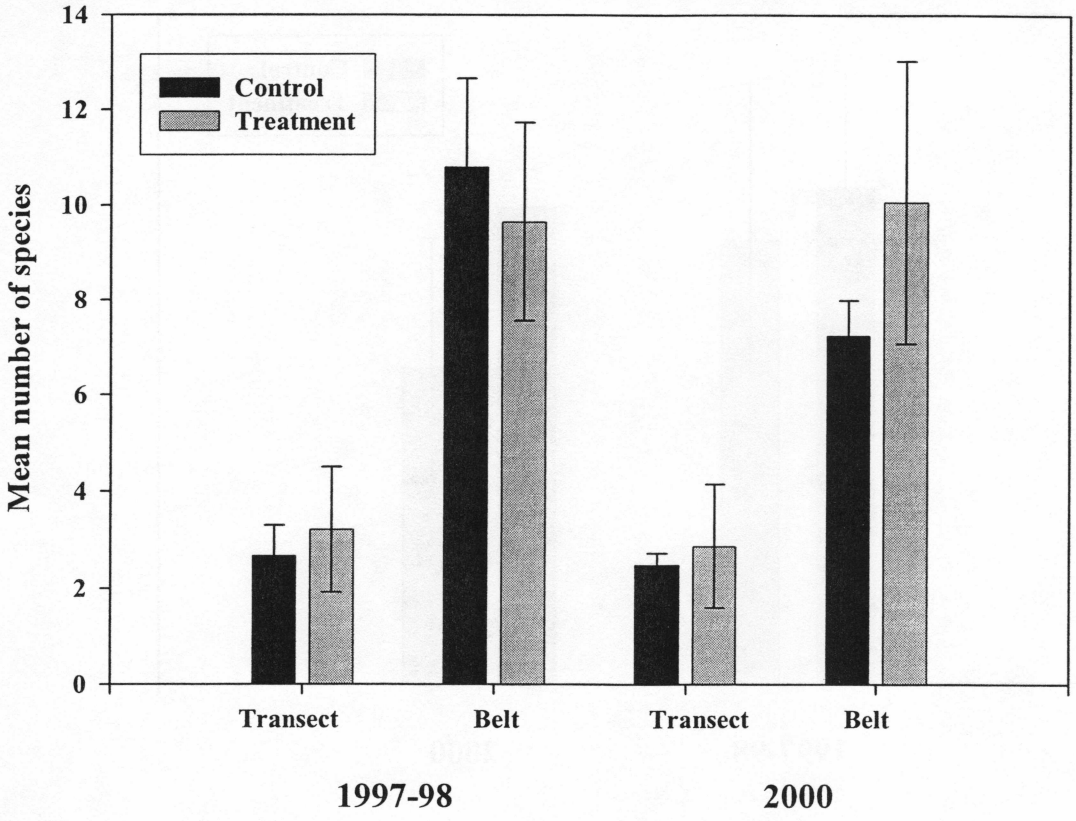


Figure 3.2. Average species richness per plot in four experimental blocks at Mt. Trumbull.

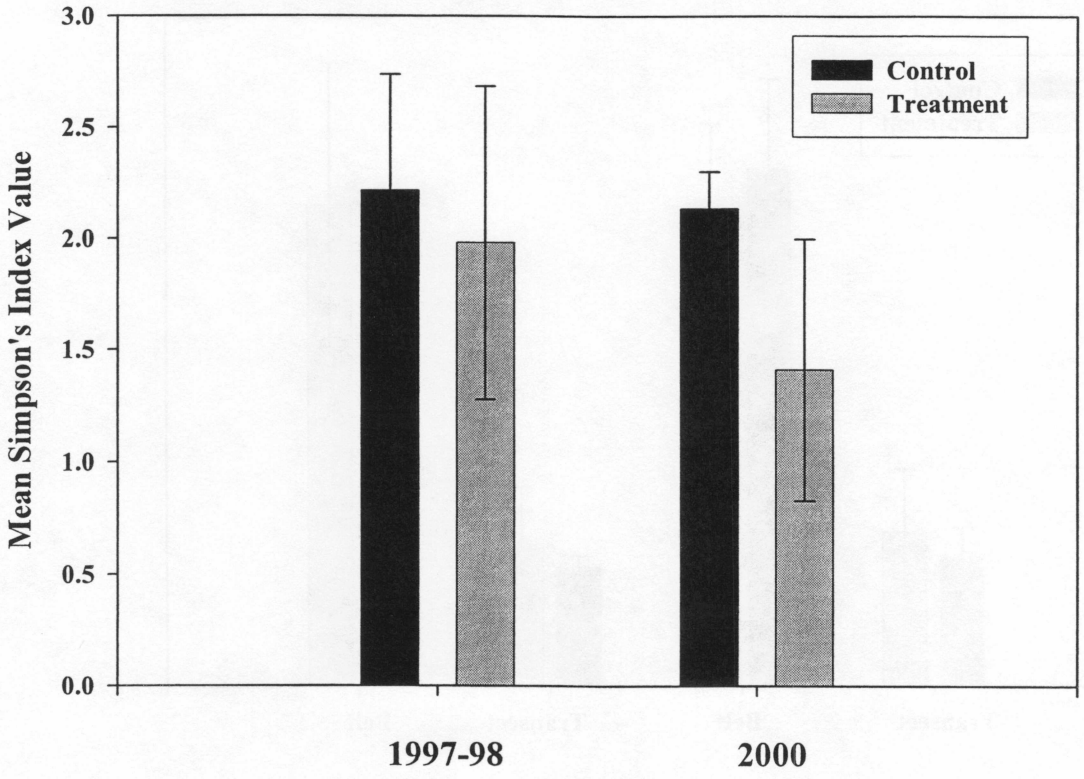


Figure 3.3. Average Simpson's diversity index (SI) per plot in 4 experimental blocks at Mt. Trumbull.

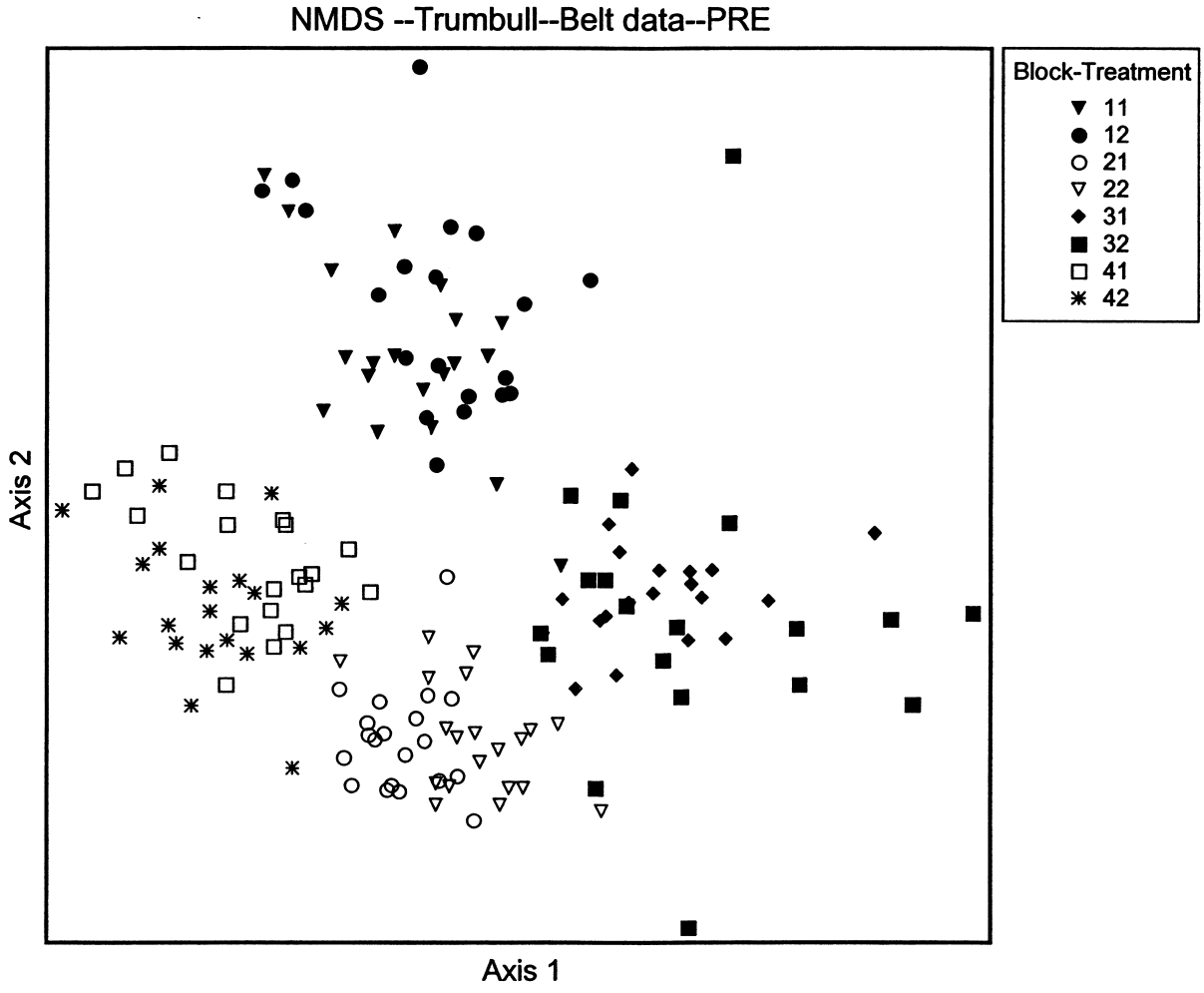

NMDS --Trumbull--Belt data--PRE
Block-Treatment
11
12
21
22
31
32
41
42
Axis 2
Axis 1

Figure 3.4

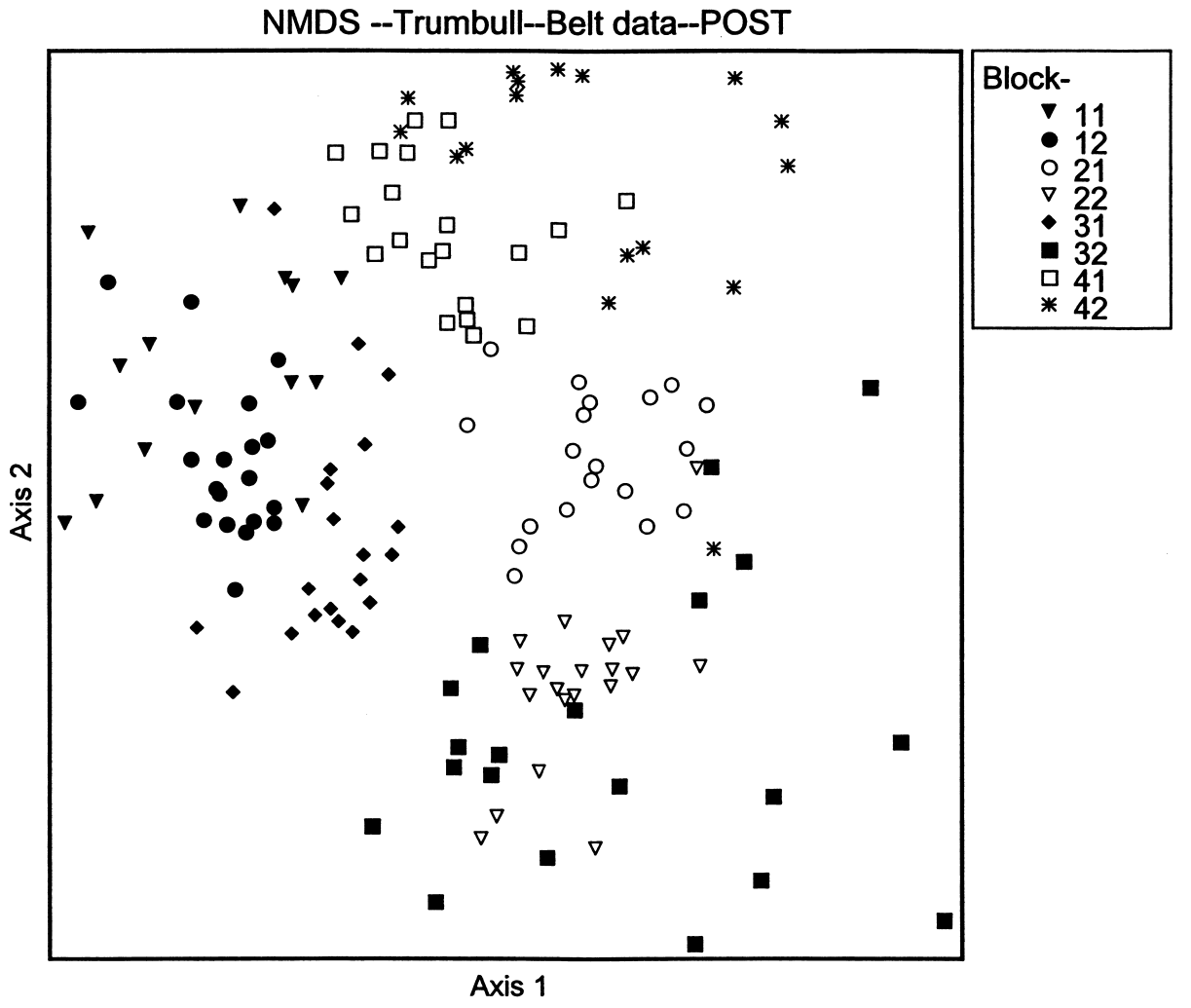

NMDS --Trumbull--Belt data--POST
Block-
11
12
21
22
31
32
41
42
Axis 2
Axis 1

Figure 3.5

Appendix I: Comprehensive species list from the experimental blocks at Mt. Trumbull.

Family	Species	Authority	Common Name	Duration	Origin	Growth Habit	Code
Anacardiaceae	*Rhus trilobata*	Nutt.	skunkbush sumac	P	N	Shrub	RHUTRI
Apiaceae	*Cymopterus purpureus*	S. Wats.	purple springparsley	P	N	Forb	CYMPUR
Apiaceae	*Lomatium foeniculaceum*	(Nutt.) Coult. & Rose	desert biscuitroot	P	N	Forb	LOMFOE
Asclepiadaceae	*Asclepias asperula*	(Decne.) Woods.	spider milkweed	P	N	Forb	ASCASP
Asclepiadaceae	*Asclepias subverticillata*	(Gray) Vail	whorled milkweed	P	N	Forb	ASCSUB
Asteraceae	*Agoseris glauca*	(Pursh) Raf.	pale agoseris	P	N	Forb	AGOGLA
Asteraceae	*Agoseris glauca var. glauca*	(Pursh) Raf.	pale agoseris	P	N	Forb	AGOGLAG
Asteraceae	*Agoseris glauca var. laciniata*	(D.C.Eat.) Smiley	false agoseris	P	N	Forb	AGOGLAL
Asteraceae	*Artemisia carruthii*	Wood ex Carruth.	Carruth's sagewort	P	N	Forb	ARTCAR
Asteraceae	*Artemisia dracunculus*	L.	tarragon	P	N	Forb	ARTDRA
Asteraceae	*Artemisia ludoviciana*	(Nutt.) Keck	white sage	P	N	Forb	ARTLUD
Asteraceae	*Artemisia tridentata*	Nutt.	big sagebrush	P	N	Shrub	ARTTRI
Asteraceae	*Bahia dissecta*	(Gray) Britt.	ragleaf bahia	B	N	Forb	BAHDIS
Asteraceae	*Brickellia californica*	(Torr. & Gray) Gray	California brickellbush	P	N	Forb	BRICAL
Asteraceae	*Brickellia eupatorioides var. chlorolepis*	(Woot. & Standl.) B.L. Turner	false boneset	P	N	Forb	BRIEUPC
Asteraceae	*Brickellia grandiflora*	(Hook.) Nutt.	tasselflower brickellbush	P	N	Forb	BRIGRA
Asteraceae	*Chrysothamnus viscidiflorus*	(Hook.) Nutt.	green rabbitbrush	P	N	Shrub	CHRVIS
Asteraceae	*Cirsium wheeleri*	(Gray) Petrak	Wheeler's thistle	P	N	Forb	CIRWHE
Asteraceae	*Conyza canadensis*	(L.) Cronq.	Canadian horseweed	A	N	Forb	CONCAN
Asteraceae	*Ericameria nauseosa ssp. nauseosa*	(Pallas ex. Pursh)	rubber rabbitbrush	P	N	Shrub	ERINAUN
Asteraceae	*Erigeron divergens*	Torr. & Gray	spreading fleabane	B	N	Forb	ERIDIV
Asteraceae	*Erigeron flagellaris*	Gray	trailing fleabane	B	N	Forb	ERIFLA
Asteraceae	*Erigeron formosissimus*	Greene	beautiful fleabane	P	N	Forb	ERIFOR
Asteraceae	*Heliomeris multiflora*	Nutt.	Showy goldeneye	P	N	Forb	HELMUL
Asteraceae	*Hymenopappus filifolius*	Hook.	fineleaf hymenopappus	P	N	Forb	HYMFIL
Asteraceae	*Hymenoxys cooperi*	(Gray) Cockerell	Cooper's hymenoxys	P	N	Forb	HYMCOO
Asteraceae	*Hymenoxys cooperi var. cooperi*	(Gray) Cockerell	Cooper's hymenoxys	B	N	Forb	HYMCOOC
Asteraceae	*Hymenoxys richardsonii*	(Hook.) Cockerell	pingue hymenoxys	P	N	Forb	HYMRIC
Asteraceae	*Lactuca serriola*	L.	prickly lettuce	P	I	Forb	LACSER

Asteraceae	*Machaeranthera canescens*	(Pursh) Gray	hoary aster	P	N	Forb	MACCAN
Asteraceae	*Packera (Senecio) multilobata*	(Torr. & Gray ex Gray) W.A. Weber & A. Love	lobeleaf groundsel	P	N	Forb	PACMUL
Asteraceae	*Senecio eremophilus*	Richards	desert ragwort	P	N	Forb	SENERE
Asteraceae	*Senecio eremophilus var. macdougalii*	(Heller) Cronq.	Macdougal's ragwort	P	N	Forb	SENEREM
Asteraceae	*Senecio multilobatus*	Torr. & Gray ex Gray	many-leaved gromwell	P	N	Forb	SENMUL
Asteraceae	*Solidago missouriensis*	Nutt.	Missouri goldenrod	P	N	Forb	SOLMIS
Asteraceae	*Solidago velutina*	DC.	threenerve goldenrod	P	N	Forb	SOLVEL
Asteraceae	*Taraxacum officinale*	G.H.Weber ex Wiggers	common dandelion	P	I	Forb	TAROFF
Asteraceae	*Townsendia incana*	Nutt.	hoary towndsendia	P	N	Forb	TOWINC
Asteraceae	*Tragopogon dubius*	Scop.	yellow salsify	AB	I	Forb	TRADUB
Berberidaceae	*Mahonia fremontii*	(Torr.) Fedde	Fremont's mahonia	P	N	Shrub	MAHFRE
Berberidaceae	*Mahonia repens*	(Lindl.) G. Don	Oregon-grape	P	N	Subshrub	MAHREP
Boraginaceae	*Cryptantha cinerea*	(Greene) Cronq.	James' cryptantha	P	N	Forb	CRYCIN
Boraginaceae	*Cryptantha cinerea var. jamesii*	Cronq.	James' catseye	P	N	Forb	CRYCINJ
Boraginaceae	*Cryptantha gracilis*	Osterhout	narrowstem cryptantha	A	N	Forb	CRYGRA
Boraginaceae	*Lappula occidentalis*	(S. Wats.) Greene	flatspine stickseed	AB	N	Forb	LAPOCC
Boraginaceae	*Lappula occidentalis var. occidentalis*	(S. Wats.) Greene	flatspine stickseed	AB	I	Forb	LAPOCCO
Boraginaceae	*Mertensia macdougalii*	Heller	Macdougal's bluebells	P	N	Forb	MERMAC
Brassicaceae	*Arabis fendleri*	Greene	fendler's rockcress	P	N	Forb	ARAFEN
Brassicaceae	*Arabis holboellii*	Hornem.	Holboell's rockcress	B	N	Forb	ARAHOL
Brassicaceae	*Chorispora tenella*	(Pallas) DC.	crossflower	A	I	Forb	CHOTEN
Brassicaceae	*Lepidium densiflorum*	Schrad.	common pepperweed	A	N	Forb	LEPDEN
Cactaceae	*Echinocereus triglochidiatus*	T.H. Kearney and R.H. Peebles	king-cup cactus	P	N	Cactus	ECHTRI
Cactaceae	*Escobaria sp.*		Arizona spineystar	P	N	Cactus	ESCO SP
Cactaceae	*Opuntia sp.*		opuntia	P	U	Cactus	OPUN SP
Caprifoliaceae	*Sambucus nigra ssp. cerulea*	(Raf.) R. Bolli	elderberry	P	N	Tree	SAMNIGC
Caprifoliaceae	*Symphoricarpos oreophilus*	Gray	whortleleaf snowberry	P	N	Shrub	SYMORE
Caprifoliaceae	*Symphoricarpos oreophilus var. utahensis*	(Rydb.) A. Nels.	Utah snowberry	P	N	Shrub	SYMOREU
Caryophyllaceae	*Arenaria eastwoodiae*	Rydb.	Eastwood's sandwort	P	N	Forb	AREEAS

Caryophyllaceae	*Arenaria fendleri*	Gray	Fendler's sandwort	P	N	Forb	AREFEN
Caryophyllaceae	*Arenaria lanuginosa*	(Michx.) Rohrb.	spreading sandwort	P	N	Forb	ARELAN
Caryophyllaceae	*Arenaria lanuginosa ssp. saxosa*	(Gray) Maguire	spreading sandwort	P	N	Forb	ARELANS
Caryophyllaceae	*Pseudostellaria jamesiana*	(Torr.) W. A. Weber & R.L. Hartman	tuber starwort	P	N	Forb	PSEJAM
Chenopodiaceae	*Chenopodium album*	L.	lambsquarters	A	N	Forb	CHEALB
Chenopodiaceae	*Chenopodium leptophyllum*	(Moq.) Nutt. ex S. Wats.	narrowleaf goosefoot	A	N	Forb	CHELEP
Convolvulaceae	*Convolvulus arvensis*	L.	field bindweed	P	I	Forb	CONARV
Convolvulaceae	*Ipomoea cristulata*	J.H. Lehr	trans-pecos morning glory	A	N	Forb	IPOCRI
Cupressaceae	*Juniperus osteosperma*	(Torr.) Little	Utah juniper	P	N	Tree	JUNOST
Cyperaceae	*Carex geophila*	Mack.	White Mountain Sedge	P	N	Graminoid	CARGEO
Cyperaceae	*Carex occidentalis*	Bailey	western sedge	P	N	Graminoid	CAROCC
Cyperaceae	*Carex vallicola*	Dewey	valley sedge	P	N	Graminoid	CARVAL
Ericaceae	*Arctostaphylos patula*	Greene	greenleaf manzanita	P	N	Shrub	ARCPAT
Ericaceae	*Arctostaphylos pungens*	Kunth	pointleaf manzanita	P	N	Shrub	ARCPUN
Euphorbiaceae	*Chamaesyce fendleri*	T.H. Kearney and R.H. Peebles	fendler's sandmat	P	N	Forb	CHAFEN
Euphorbiaceae	*Chamaesyce serpyllifolia*	(Pers.) Small	thymeleaf sandmat	A	N	Forb	CHASER
Euphorbiaceae	*Euphorbia albomarginata*	(Torr. & Gray)	Small whitemargin sandmat	P	N	Forb	EUPALB
Euphorbiaceae	*Euphorbia brachycera*	Engelm.	horned spurge	P	N	Forb	EUPBRA
Euphorbiaceae	*Euphorbia incisa*	Engelm.	Mohave spurge	P	N	Forb	EUPINC
Euphorbiaceae	*Euphorbia lurida*	Engelm.	San Francisco Mtn. spurge	P	N	Forb	EUPLUR
Fabaceae	*Astragalus argophyllus*	Nutt.	silverleaf milkvetch	P	N	Forb	ASTARG
Fabaceae	*Astragalus castaneiformis*	S. Wats.	chestnut milkvetch	P	N	Forb	ASTCAS
Fabaceae	*Lathyrus laetivirens*	Greene ex Rydb.	aspen peavine	P	N	Forb	LATLAE
Fabaceae	*Lathyrus lanszwertii var. leucanthus*	(Rydb.) Dorn	Nevada pea	P	N	Forb	LATLANL
Fabaceae	*Lotus plebeius*	(Brand) Barneby	New Mexico bird's-foot trefoil	P	N	Forb	LOTPLE
Fabaceae	*Lotus utahensis*	Ottley	Utah birdsfoot trefoil	P	N	Forb	LOTUTA
Fabaceae	*Lotus wrightii*	(Gray) Greene	Wright's deervetch	P	N	Forb	LOTWRI
Fabaceae	*Lupinus argenteus*	Pursh	silver lupine	P	N	Forb	LUPARG
Fabaceae	*Lupinus kingii*	S. Wats.	Kings Lupine	A	N	Forb	LUPKIN
Fabaceae	*Medicago sativa*	L.	alfalfa	P	I	Forb	MEDSAT
Fabaceae	*Psoralidium tenuiflorum*	(Pursh.) Rydb.	slimflower scurfpea	P	N	Forb	PSOTEN

Fabaceae	*Robinia neomexicana*	Gray	New Mexico locust	P	N	Tree	ROBNEO
Fabaceae	*Vicia americana*	Muhl. ex Willd.	American vetch	P	N	Forb	VICAME
Fagaceae	*Quercus gambelii*	Nutt.	Gambel oak	P	N	Tree	QUEGAM
Fagaceae	*Quercus turbinella*	Greene	shrub live oak	P	N	Shrub	QUETUR
Fumiariaceae	*Corydalis aurea*	Willd.	golden corydalis	A	N	Forb	CORAUR
Gentianaceae	*Frasera speciosa*	Dougl. ex Griseb.	showy frasera	P	N	Forb	FRASPE
Geraniaceae	*Geranium caespitosum*	James	pineywoods geranium	P	N	Forb	GERCAE
Grossulariaceae	*Ribes cereum*	Dougl.	wax currant	P	N	Shrub	RIBCER
Hydrophyllaceae	*Phacelia heterophylla*	Pursh	varileaf phacelia	BP	N	Forb	PHAEGE
Lamiaceae	*Dracocephalum parviflorum*	Nutt.	American dragonhead	AB	N	Forb	DRAPAR
Lamiaceae	*Leonurus cardiaca*	(L.)	common motherwort	P	I	Forb	LEOCAR
Lamiaceae	*Marrubium vulgare*	L.	horehound	P	I	Forb	MARVUL
Lamiaceae	*Monardella odoratissima*	Benth.	Pacific monardella	P	N	Forb	MONODO
Liliaceae	*Allium bisceptrum*	(S. Wats.) Cronq.	aspen onion	P	N	forb	ALLBIS
Liliaceae	*Allium bisceptrum var. palmeri*	(S. Wats.) Cronq.	aspen onion	P	N	Forb	ALLBISP
Liliaceae	*Calochortus nuttallii*	Torr. & Gray	sego lily	P	N	Forb	CALNUT
Liliaceae	*Fritillaria atropurpurea*	Nutt.	spotted missionbells	P	N	Forb	FRIATR
Loasaceae	*Mentzelia dispersa*	S. Wats.	bushy blazingstar	A	N	Forb	MENDIS
Monotropaceae	*Pterospora andromedea*	Nutt.	woodland pinedrops	P	N	Forb	PTEAND
Nyctaginaceae	*Mirabilis decipiens*	(Standl.) Standl.	broadleaf four o'clock	P	N	Forb	MIRDEC
Nyctaginaceae	*Mirabilis linearis*	(Pursh) Heimerl.	narrowleaf four o'clock	P	N	Forb	MIRLIN
Nyctaginaceae	*Mirabilis oxybaphoides*	(Gray) Gray	smooth spreading four o'clock	P	N	Forb	MIROXY
Onagraceae	*Epilobium angustifolium*	L.	fireweed	P	N	Forb	EPIANG
Onagraceae	*Epilobium brachycarpum*	K. Presl.	tall annual willowherb	A	N	Forb	EPIBRA
Onagraceae	*Gayophytum diffusum*	Torr. & Gray	spreading groundsmoke	A	N	Forb	GAYDIF
Onagraceae	*Gayophytum diffusum ssp. parviflorum*	Lewis & Szweykowski	spreading groundsmoke	A	N	Forb	GAYDIFP
Onagraceae	*Oenothera caespitosa*	Nutt.	tufted eveningprimrose	P	N	Forb	OENCAE
Papaveraceae	*Argemone munita*	Dur. & Hilg.	flatbud pricklypoppy	P	N	Forb	ARGMUN
Pinaceae	*Pinus edulis*	Engelm.	pinyon pine	P	N	Tree	PINEDU
Pinaceae	*Pinus ponderosa*	P. & C. Lawson	ponderosa pine	P	N	Tree	PINPON
Poaceae	*Achnatherum hymenoides*	(Roemer & J.A. Schultes) Barkworth	Indian ricegrass	P	N	Graminoid	ACHHYM
Poaceae	*Aegilops cylindrica*	Host	jointed goatgrass	A	I	Graminoid	AEGCYL
Poaceae	*Agropyron sp.*		wheatgrass	P	U	Graminoid	AGRO SP

Poaceae	*Aristida purpurea*	Nutt.	purple threeawn	P	N	Graminoid	ARIPUR
Poaceae	*Blepharoneuron tricholepis*	(Torr.) Nash	pine-dropseed	P	N	Graminoid	BLETRI
Poaceae	*Bouteloua gracilis*	(Willd. ex Kunth) Lag. ex Griffiths	blue grama	P	N	Graminoid	BOUGRA
Poaceae	*Bromus inermis*	Leyss.	smooth brome	P	I	Graminoid	BROINE
Poaceae	*Bromus tectorum*	L.	cheatgrass	A	I	Graminoid	BROTEC
Poaceae	*Elymus elymoides ssp. elymoides*	(Raf.) Swezey	squirreltail	P	N	Graminoid	ELYELYE
Poaceae	*Elymus trachycaulus ssp. trachycaulus*	(Link) Gould ex Shinners	slender wheatgrass	P	N	Graminoid	ELYTRAT
Poaceae	*Festuca arizonica*	Vasey	Arizona fescue	P	N	Graminoid	FESARI
Poaceae	*Hesperostipa comata*	(Trin. & Rupr.) Barkworth	needle & thread	P	N	Graminoid	HESCOM
Poaceae	*Koeleria macrantha*	(Ledeb.) J.A. Schultes	prairie junegrass	P	N	Graminoid	KOEMAC
Poaceae	*Muhlenbergia montana*	(Nutt.) A.S. Hitchc.	mountain muhly	P	N	Graminoid	MUHMON
Poaceae	*Pascopyrum smithii*	(Rydb.) A. Love	western wheatgrass	P	N	Graminoid	PASSMI
Poaceae	*Poa fendleriana*	(Steud.) Vasey	muttongrass	P	N	Graminoid	POAFEN
Poaceae	*Poa pratensis*	L.	Kentucky bluegrass	P	I	Graminoid	POAPRA
Poaceae	*Schizachyrium scoparium*	(Michx.) Nash	little bluestem	P	N	Graminoid	SCHSCO
Poaceae	*Thinopyrum intermedium*	(Host) Barkworth & D.R. Dewey	intermediate wheatgrass	P	I	Graminoid	THIINT
Polemoniaceae	*Ipomopsis aggregata*	(Pursh) V. Grant	skyrocket gilia	B	N	Forb	IPOAGG
Polemoniaceae	*Ipomopsis aggregata ssp. aggregata*	(Pursh) V. Grant	scarlet gilia	PB	N	Forb	IPOAGGA
Polemoniaceae	*Phlox gracilis*	(Hook.) Greene	slender phlox	A	N	Forb	PHLGRA
Polemoniaceae	*Phlox longifolia*	Nutt.	longleaf phlox	P	N	Forb	PHLLON
Polygonaceae	*Eriogonum alatum*	Torr.	winged buckwheat	P	N	Forb	ERIALA
Polygonaceae	*Eriogonum pharnaceoides*	Torr.	wirestem buckwheat	A	N	Forb	ERIPHA
Polygonaceae	*Eriogonum racemosum*	Nutt.	redroot buckwheat	P	N	Forb	ERIRAC
Polygonaceae	*Eriogonum umbellatum*	Torr.	sulphur wildbuckwheat	P	N	Forb	ERIUMB
Polygonaceae	*Polygonum convolvulus*	L.	black bindweed	A	I	Forb	POLCON
Polygonaceae	*Polygonum douglasii*	Greene	Douglas' knotweed	A	N	Forb	POLDOU
Polygonaceae	*Polygonum douglasii ssp. johnstonii*	(Munz) Hickman	Johnston's knotweed	A	N	Forb	POLDOUJ
Polypodiaceae	*Cystopteris fragilis*	(L.) Bernh.	brittle bladderfern	P	N	Fern	CYSFRA
Portulacaceae	*Claytonia lanceolata*	Pursh.	lanceleaf springbeauty	P	N	Forb	CLALAN
Ranunculaceae	*Delphinium nuttallianum*	Pritz. ex Walp.	twolobe larkspur	P	N	Forb	DELNUT

Ranunculaceae	*Delphinium nuttallianum var. nuttallianum*	Pritz. ex Walp.	Nuttal's larkspur	P	N	Forb	DELNUTN
Ranunculaceae	*Ranunculus oreogenes*	Greene	Oregon buttercup	P	N	Forb	RANORE
Ranunculaceae	*Thalictrum fendleri*	Engelm. ex Gray	Fendler's meadowrue	P	N	Forb	THAFEN
Rhamnaceae	*Ceanothus fendleri*	Gray	Fendler's ceanothus	P	N	Shrub	CEAFEN
Rhamnaceae	*Ceanothus martinii*	M.E. Jones	Martin's ceanothus	P	N	Shrub	CEAMAR
Rosaceae	*Amelanchier alnifolia*	(Nutt.) ex M. Roemer	Saskatoon serviceberry	P	N	Shrub	AMEALN
Rosaceae	*Amelanchier utahensis*	Koehne	Utah serviceberry	P	N	Shrub	AMEUTA
Rosaceae	*Fallugia paradoxa*	(D. Don) Endl. ex Torr.	Apacheplume	P	N	Shrub	FALPAR
Rosaceae	*Purshia mexicana*	(D. Don) Henrickson	Mexican cliffrose	P	N	Shrub	PURMEX
Rosaceae	*Purshia tridentata*	(Pursh) DC.	antelope bitterbrush	P	N	Shrub	PURTRI
Rubiaceae	*Galium bifolium*	S. Wats.	twinleaf bedstraw	A	N	Forb	GALBIF
Santalaceae	*Comandra umbellata ssp. pallida*	(A. DC.) Piehl	pale bastard toadflax	P	N	Forb	COMUMBP
Scrophulariaceae	*Castilleja sp.*		Indian paintbrush	P	N	Forb	CAST SP
Scrophulariaceae	*Collinsia parviflora*	Lindl.	smallflower blue eyed Mary	A	N	Forb	COLPAR
Scrophulariaceae	*Cordylanthus parviflorus*	(Ferris) Wiggins	purple bird's beak	A	N	Forb	CORPAR
Scrophulariaceae	*Mimulus rubellus*	Gray	red monkeyflower	A	N	Forb	MIMRUB
Scrophulariaceae	*Pedicularis centranthera*	Gray	dwarf lousewort	P	N	Forb	PEDCEN
Scrophulariaceae	*Penstemon barbatus*	(Cav.) Roth	beardlip penstemon	P	N	Forb	PENBAR
Scrophulariaceae	*Penstemon linarioides*	Gray	toadflax penstemon	P	N	Forb	PENLIN
Scrophulariaceae	*Penstemon nudiflorus*	Gray	Flagstaff beardtongue	P	N	Forb	PENNUD
Scrophulariaceae	*Penstemon pachyphyllus*	Gray ex Rydb.	thick-leaf beardtongue	P	N	Forb	PENPAC
Scrophulariaceae	*Penstemon palmeri*	Gray	Palmer's penstemon	P	N	Forb	PENPAL
Scrophulariaceae	*Penstemon rostriflorus*	Kellogg	Bridge penstemon	P	N	Forb	PENROS
Scrophulariaceae	*Penstemon virgatus*	Gray	upright blue beardtongue	P	N	Forb	PENVIR
Scrophulariaceae	*Verbascum thapsus*	L.	common mullein	B	I	Forb	VERTHA
Solanaceae	*Nicotiana attenuata*	Torr. ex S. Wats.	coyote tobacco	A	N	Forb	NICATT
Solanaceae	*Physalis hederifolia*	Gray	ivyleaf ground cherry	P	N	Forb	PHYHED
Solanaceae	*Physalis hederifolia var. palmeri*	(Gray) Cronq.	Palmer's groundcherry	P	N	Forb	PHYHEDP
Verbenaceae	*Glandularia gooddingii*	(Briq.) Solbrig	southwestern mock vervain	P	N	Forb	GLAGOO
Violaceae	*Viola canadensis*	L.	Canadian white violet	P	N	Forb	VIOCAN

Chapter 4. Wildfire and Restoration Treatment Results

Introduction

This final chapter compares an unplanned treatment; a wildfire, with a paired restoration treatment and a similar, untreated forest stand. This comparison is unique because pre-treatment data were available on the unit that was burned by wildfire.

There are multiple management options ranging from thinning and burning to full fire suppression available to land managers of ponderosa pine forests. Along with minimal thinning, burn-only treatments and full fire suppression, one option is to provide no management, allowing fires to burn and leaving the forest to rejuvenate naturally following a crown-replacing wildfire. Advocates of this management style reason that the ecosystem will rebound to a naturally functioning system, regardless of the 100 years of forest degradation due to fire suppression, logging and grazing. However, this method is difficult to test and impossible to experiment with close to private property or townships. Most studies studying the effects of wildfire have no pre-treatment data. These studies usually pair wildfire sites with unburned adjacent forests, based on assumptions of similarity prior to the wildfire. The crowning wildfire in Block 3 provided an opportunity to look at changes in forest structure due to wildfire and restoration treatment in similar forests. A new control was selected that was comparable with the pre-treatment data from both the wildfire and restoration treatment units.

The dendrochronological data and fire history evidence at Mt. Trumbull does not suggest that crown fires occurred in at least the last 400 years. Fire scars show re-occurring fire every 4 – 7 years at the Mt. Trumbull RCA (Fulé, unpublished data). Tree stand structure show mixed-aged stands, and not the even-aged stands characteristic of crown-replacing, high intensity fires (Waltz, chapter 1). However, present-day crown fires could occur with current tree densities and fuel loadings under common weather conditions (Fulé, chapter 2). Under these current conditions, fires from natural starts burn at intensity levels far greater than fires in the same forests 100 years ago. High intensity fires cause tree mortality in large areas, either immediately through torching and heat scorch, or slower mortality due to heat girdling of the cambium layer. Wildfires can also cause nutrient loss due to volatilization, tree species compositional changes, soil erosion and reduction in dead, woody material (Grier 1975, Campbell et all. 1977, Neary et al. 1996, Fulé et al. 2000).

This study is unique because of the pre-treatment data and because it is paired with a restoration treatment, allowing side-by-side comparisons through time. Although questions concerning tree regeneration and understory responses may take years or even decades to address (Stickney 1986, Foxx 1996), the changes in forest structure can be assessed one year following treatments. Overall tree density and composition following wildfire and restoration treatments contribute significantly to future tree regeneration patterns, and understory plant colonization. We used this natural experiment to ask one general question 1. What forest structural changes occurred with wildfire and with restoration treatments, and how do they differ?

Methods

This study took place in experimental block 3 of the Mt. Trumbull restoration project. At the highest elevation, block 3 was dominated by large, presettlement ponderosa pine, but also had Gambel oak and New Mexican locust throughout the unit. This unit is one of the largest (~100 acres) and is predominately on cinder soils. Pre-treatment data was collected in 1998 from 40 plots, 20 each in a randomly assigned restoration treatment unit and control (see general methods for plot descriptions and measurements).

The restoration treatment unit was thinned in 1999 as part of a commercial logging sale. It was burned March 2000 under prescription. One week later, high winds kicked up flames from a smoldering stump located in an adjacent wilderness treatment unit (trees cut but left on site), igniting fire into the unburned control unit. With the high winds, unthinned forests and high forest floor fuel build-up, this fire was not within natural fire prescriptions, and full suppression was implemented. The fire torched in several areas throughout the control, and high flame lengths and heat resulted in scorch rates of up to 100%.

Both the restoration treatment unit, the wildfire treatment unit and the newly established control were remeasured in June 2000. On remeasured plots, tree condition, scorch height, scorch percentage, and minimal and maximum char height were recorded, in addition to original plot measurements. The new control was established in an area with tree densities, tree composition, and soil type comparable to pre-treatment wildfire and restoration treatment units. Twenty plots were placed in the new control, and all pre-treatment data collected (see general methods).

Results

Forest structural changes: Both the restoration treatment and the wildfire significantly reduced tree densities and basal area per hectare, and there were no significant differences in tree densities or basal area between the wildfire and restoration treatment units (Tables 4.1, 4.2). The wildfire reduced approximately 77% of the stems per hectare, while the restoration treatment removed approximately 84% of the stems. Basal area was reduced by similar amounts in the wildfire and restoration treatments; both were approximately 55% less than the pre-treatment values.

Although the total numbers suggest that wildfire and restoration treatments have very similar effects on forest structure, the wildfire reduced compositional diversity (Table 4.1) and killed the largest and oldest trees in the unit (Figures 4.1, 4.2). The restoration treatment design removed only ponderosa pine trees through thinning, and only trees that established since the date of the last fire. The prescribed fire caused tree mortality in all tree species, resulting in oak, juniper, pinyon pine and additional ponderosa pine mortality. Restoration treatment reduced ponderosa pine densities by 84%, Gambel oak by 64% and New Mexican locust by 89%. The wildfire reduced ponderosa pine densities only by 60%, but reduced Gambel oak by 86% and New Mexican locust almost 100% (Table 4.1). The resulting stand following the wildfire was 96% ponderosa pine versus 71% ponderosa pine in the restoration treatment.

The wildfire also removed all the ponderosa pines greater than 65 cm in diameter - approximately 11 trees per hectare. The oldest living tree after the wildfire had a center date of 1850 while age classes going back to the 1400's were killed. In contrast, the restoration treatment retained the largest and oldest trees, with trees as large as 105 cm in diameter, and with establishment dates as old as 1470 (Figures 4.1, 4.2).

Canopy cover: Canopy cover was reduced by 56% in the restoration treatment unit. Canopy cover did not show differences in the wildfire. This surprising result can be attributed to 2 factors: 1. both dead and live tree canopy cover were recorded as canopy present, and 2. most trees retained their needles. For example, trees killed by scorch retain brown needles the first year following the fire. Canopy cover is still present in these cases and identical to pre-wildfire cover. Needles were predicted to fall in the second year following wildfire, with corresponding decreases in canopy cover.

Regeneration: Ponderosa pine regeneration was eliminated by both the restoration treatment and the wildfire (Table 4.4). Sprouting trees (Gambel oak, New Mexican locust) showed variable responses when looking at all regeneration less than breast height (1.4 m). However, the size class distribution of sprouting trees was significantly altered by both the wildfire and the restoration treatments. The density of regeneration was spread fairly evenly across the three size classes measured prior to treatments (Table 4.4). Following the treatments, the largest size classes showed significantly less regeneration densities than prior to treatment. In contrast, the smallest size classes showed increases up to 5 times as high as pretreatment levels. In conclusion, although total deciduous tree regeneration did not change, the larger classes were fire killed, and the smaller size classes increased immediately following the fire.

Fuels: (Table 4.5) Total fuel loadings showed no significant differences in fuel loadings for both treatments. Measurements of fuels are highly variable (note standard error values in Table 4.5). However, trends show an overall 55% ***decrease*** in forest fuels following the wildfire, and an overall 23% ***increase*** following restoration treatment. The intensity of the wildfire did significantly decreased the fine fuels (duff, 1 Hour and 10 Hour fuels), but also showed decreasing trends in the larger diameter class downed wood (100 Hour – 1000 Hour fuel classes). The restoration treatment significantly decreased some fine fuels (litter and duff), but added to or did not change the larger size class woody fuels. Additions of larger fuel classes occur through the logging and thinning operations. Commercial loggers remove "take" trees larger than 6-inch diameters. These trees are de-limbed on site, and this slash material is left on the ground. The remaining small diameter trees that are marked for removal are felled and left on site, also contributing to total fuel loads.

Discussion

Restoration treatments and crowning wildfire alter forest structure in different ways. While total tree density and total basal area numbers may not differ following these two treatments, these data suggest wildfire reduced compositional diversity and age-class diversity when compared with restoration treatments. Tree survival of wildfire is highest among trees with fire resistance traits (pines), such as thick bark and high foliage.

Survival is low for individual trees with fire resilience traits rather than resistance, such as oaks and locust. However, these species resprout readily after wildfire. The proportion of ponderosa pine in the stand changed from 53% prior to the wildfire to almost 96% following the wildfire. Restoration treatment, in contrast, retained the stand composition and maintained the proportion of the stand represented by ponderosa pine (~70% ponderosa pine before and after restoration treatment).

Tree regeneration and future stand structure in both treatments will only be determined with time. However, wildfire regeneration creates even-aged stands. The regeneration in these stands slows as the initial age class grows. As a result, these post-wildfire stands may result in the dense forests observed today. Conversely, while the restoration treatments show low mortality of old-growth initially, higher mortality due to treatments may still become evident over the next 3 – 7 years.

Future studies will include the herbaceous and regeneration response to wildfire and restoration treatments. Tree compositional shifts such as those caused by the EB3 wildfire have cascading effects on higher trophic levels. Avian and mammal usage of oak and locust plants was high in these forests. Although oaks and locust resprout rapidly, the original structure of the oak will not be evident for 20 – 50 years. Other studies predict the understory will show increased production (Moore and Deiter 1992, Oswald and Covington 1983, Stickney 1986, Covington et al. 1997).

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Table 4.1 Trees per hectare on Block 3, prior to and post restoration treatment and wildfire. Control 2000 was established in 2000, and was chosen because of its similarity to pre-treatment structure in the wildfire and restoration treatment units.

	1998 Pre-treatment		2000 Post-treatment		
	Wildfire	Treatment	Control 2000	Wildfire	Treatment
PIPO	507.5 (134.24)	621.3 (123.78)	612.5 (140.2)	207.5 (76.26)	100.0 (17.3)
QUGA	43.8 (22.86)	52.5 (29.24)	42.5 (18.06)	6.3 (3.08)	18.8 (8.29)
RONE	392.5 (164.37)	201.3 (90.4)	76.3 (32.52)	1.3 (1.25)	21.3 (16.35)
JUOS	1.3 (1.25)	1.3 (1.25)	3.8 (2.74)	1.3 (1.25)	0
PIED	6.3 (3.08)	1.3 (1.25)	2.5 (1.72)	0	0
Total	951.3 (183.82)	877.5 (118.96)	737.5 (133.84)	216.3 (75.79)	140 (16.16)

Table 4.2 Basal area per hectare on Block 3, prior to and post restoration treatment and wildfire.

	1998 Pre-treatment		2000 Post-treatment		
	Wildfire	Treatment	Control 2000	Wildfire	Treatment
PIPO	29.5 (3.91)	38.3 (4.50)	25.4 (3.07)	14.0 (3.80)	16.1 (3.73)
QUGA	0.5 (0.31)	1.0 (0.44)	1.4 (0.67)	0.1 (0.09)	0.4 (0.19)
RONE	0.05 (0.023)	0.4 (0.42)	0.2 (0.12)	0 (0)	0.4 (0.42)
JUOS	0.09 (0.090)	0.01 (0.011)	0.02 (0.023)	0.09 (0.09)	0
PIED	0.2 (0.09)	0.04 (0.035)	0.01 (0.012)	0	0
Total	30.4 (3.82)	39.7 (4.30)	27.0 (3.09)	14.2 (3.82)	17.0 (3.62)

Table 4.4. Canopy cover in Block 3. Note: canopy is measured from live and dead trees.

	Wildfire	Treatment	Control 2000
Pre-treatment	47.6 (4.55)	49.3 (4.81)	n/a
Post-treatment	45.7 (3.26)	21.5 (3.57)	47.9 (4.19)

Table 4.4 Regeneration per hectare on Block 3

			1998 Pre-treatment				2000 Post-treatment			
Block	**Treatment**	**Species**	**Total**	**0 – 40 cm**	**40 – 80 cm**	**80 – 137 cm**	**Total**	**0 – 40 cm**	**40 – 80 cm**	**80 – 137 cm**
3	**Wildfire**	PIPO	**25** (12.3)	**10** (6.9)	**5** (5)	**10** (10)	**0**	**0**	**0**	**0**
		QUGA	**15** (8.2)	**15** (8.2)	**0**	**0**	**45** (30.3)	**45** (30.3)	**0**	**0**
		RONE	**2410** (1030)	**745** (404.1)	**1090** (517.8)	**575** (213.8)	**2410** (955.4)	**2040** (915.4)	**300** (140.0)	**70** (48.7)
		PIED	**5** (5)	**0**	**5** (5)	**0**	**0**	**0**	**0**	**0**
3	**Treatment**	PIPO	**30** (20.6)	**20** (15.6)	**5** (5)	**5** (5)	**0**	**0**	**0**	**0**
		QUGA	**100** (47.6)	**100** (47.6)	**0**	**0**	**110** (64.0)	**105** (59.6)	**5** (5.0)	**0**
		RONE	**685** (380.1)	**255** (171.9)	**295** (161.3)	**135** (67.8)	**1300** (685.7)	**1015** (535.7)	**265** (147.5)	**20** (11.7)
		PIED	**5** (5)	**5** (5)	**0**	**0**	**5** (5.0)	**5** (5.0)	**0**	**0**
3	**Control 2000**	PIPO					**95** (25.6)	**35** (16.7)	**45** (11.4)	**15** (8.2)
		QUGA					**710** (570.6)	**690** (561.2)	**20** (13.8)	**0**
		RONE					**225** (121.2)	**75** (42.8)	**85** (41.8)	**65** (45.5)
		PIED					**10** (6.9)	**5** (5.0)	**5** (5.0)	**0**

Block	Treatment	Treatment Status	Litter (cm)	Duff (cm)	1H (Mg/ha)	10H (Mg/ha)	100H (Mg/ha)	1000H sound (Mg/ha)	1000H rotten (Mg/ha)	Total Wood (Mg/ha)
3	**Wildfire**	Pre-treat	**0.83** (0.10)	**4.17** (0.38)	**0.33** (0.08)	**2.33** (0.39)	**2.15** (0.85)	**13.9** (9.30)	**9.20** (5.78)	**27.9** (14.3)
		Post-treat	**0.87** (0.22)	**0.66** (0.17)	**0.04** (0.016)	**0.35** (0.12)	**0.29** (0.197)	**11.8** (9.14)	**0**	**12.5** (9.18)
3	**Treatment**	Pre-treat	**0.88** (0.12)	**4.06** (0.50)	**0.14** (0.05)	**1.49** (0.43)	**1.58** (0.49)	**4.04** (1.62)	**9.25** (5.62)	**16.5** (5.91)
		Post-treat	**0.47** (0.06)	**1.05** (0.14)	**0.11** (0.03)	**1.25** (0.29)	**3.88** (0.87)	**15.0** (3.73)	**0**	**20.3** (4.01)
3	**Control 2000**	Post-treat	**1.92** (0.28)	**3.87** (0.57)	**0.27** (0.06)	**0.89** (0.19)	**1.58** (0.49)	**3.86** (2.21)	**14.4** (9.44)	**21.0** (11.6)

Table 4.5. Forest floor fuels.

Figure 4.1. Diameter distribution of Block 3.

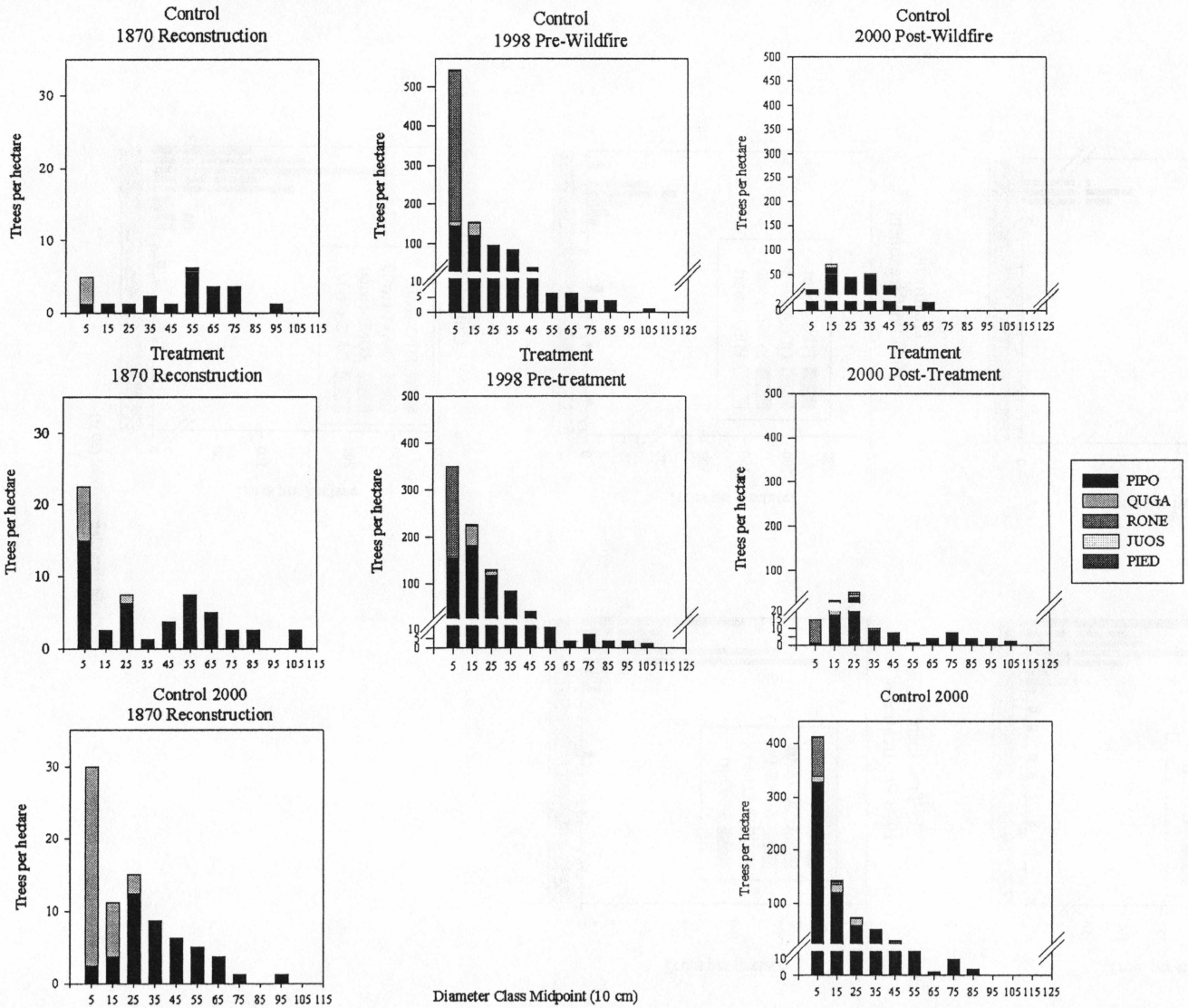


Figure 4.2. Age distribution of Block 3.

