Accelerating Development of Late-Successional Features in Second-Growth Pine Stands of the Goosenest Adaptive Management Area[1]

Martin W. Ritchie[2] and Kathleen A. Harcksen[3]

Abstract

This paper describes implementation and early results of a large-scale, interdisciplinary experiment in the Goosenest Adaptive Management Area in northeastern California. The study is designed to investigate development of late-successional forest attributes in second-growth ponderosa pine stands. The experiment has four treatments replicated five times and encompasses 1600 hectares, including controls. Complete treatment implementation took five years, including application of prescribed fire. Initial post-treatment measurements were conducted in 2002. Change in quadratic mean diameter averaged 12.5 cm among thinned stands. Initial estimates of post-treatment growth from remeasured diameters indicate little immediate impact of treatments on individual tree growth. However increment cores from dominant trees showed an increase in diameter growth by 11 to 14 percent in the treated plots during the first three years after treatment. Quadratic mean diameter in thinned stands was still well below that reported in reference old-growth stands. Among those stands treated with a targeted change in species composition, the mean treatment effect was an increase of 16 percent in proportion of pine basal area, with a range from 6 to 29 percent. The control treatment and thin from below treatment showed no significant change in species composition. The initial application of prescribed fire resulted in little mortality (less than 1 percent for large trees) and had no immediate impact on the diameter distribution. Logging damage observed on residual trees varied between 2 and 6 percent, depending on treatment and tree size.

Introduction

The Northwest Forest Plan (USDA and USDI 1994a) ushered in a new era for forest management on federal land in the Pacific Northwest. Intended to implement management strategies that would be more favorable to the meet the habitat requirements of the northern spotted owl (*Strix occidentalis caurina*), the Plan changed management emphasis for millions of acres of forests in Washington, Oregon and northern California. One requirement of the Record of Decision (USDA and USDI 1994b) of the Northwest Forest Plan was to establish a network of

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[2] Biometrician, Pacific Southwest Research Station, Redding Silviculture Laboratory, 3644 Avtech Parkway, Redding CA 96002, (email: mritchie@fs.fed.us)
[3] Silviculturist, Parashant National Monument, Arizona Strip BLM, 345 East Riverside Drive, St. George UT 84790, (email: harcksen@blm.gov)

Adaptive Management Areas, thus providing managers opportunities to develop and test innovative strategies to meet management objectives.

The Goosenest Adaptive Management Area is located in northern California on the Klamath National Forest. One of the primary objectives of the Goosenest AMA is to evaluate "…the development of ecosystem management approaches, including the use of prescribed burning and other silvicultural techniques for management of pine forest including objectives related to forest health, production and maintenance of late-successional forest and riparian habitat, and commercial timber production" (USDA and USDI 1994b; Page D-13).

Harvesting in the early 1930s removed the largest and most valuable pines and most of the larger white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.). The land was transferred to the Klamath National Forest in the 1950s. Subsequently, some of the area received precommercial thinning and sanitation/salvage treatments.

The historic fire return interval in these stands created an environment favoring ponderosa pine (*Pinus ponderosa* P. & C. Lawson), a long-lived species well adapted to frequent low-intensity fires (Skinner and Chang 1996). The harvest of overstory pine trees and the elimination of fire from the ecosystem have significantly changed the size and species distributions of trees throughout the AMA.

Forests in this area are naturally regenerated second-growth stands with ponderosa pine and white fir as the primary tree species. There are lesser amounts of sugar pine (*Pinus lambertiana* Dougl.), incense-cedar (*Calocedrus decurrens* (Torr.) Florin) and red fir (*Abies magnifica* A. Murr.) at the higher elevations. Historically this area featured open park-like stands dominated by large ponderosa pine trees. Measured in 2004, breast-height age of dominant, site quality, pine averages 64 years with a range from 49 to 85. There is a component of 200+ year old trees scattered through the overstory, however the heights indicate that these were subdominant (intermediate crown class) trees in 1930, and released by the initial harvests. These trees have diameters and heights very similar to those of the trees that regenerated after overstory removal.

In 1995, the Klamath National Forest and the Pacific Southwest Research Station entered into a partnership to establish a study on the AMA to address key issues stated in the Record of Decision. An interdisciplinary research team, engaged in work at Blacks Mountain Experimental Forest (Oliver and Powers 1998, Oliver 2000), began working with managers from the Goosenest Ranger District to investigate problems and potential treatments to evaluate on the AMA. The research team considered a range of issues relating to development of late-successional forest conditions. The resulting project is a long-term study geared to evaluating the effects of large-scale treatments designed to accelerate tree growth, create more open stand conditions and re-introduce fire to the system (Ritchie and Harcksen 1999, Ritchie 2005). Our study will provide information to managers and researchers seeking a better understanding of the consequences of various management strategies in stands with a similar treatment history and species composition.

This paper describes treatment implementation and presents some early treatment effects on vegetation and coarse woody debris.

Methods

Study Design

The research team focused on three key factors in designing this study: species composition, distribution of trees by diameter class, and the role of fire in this system. In order to accelerate late successional stand attributes we wish to create stands with (1) a higher proportion of ponderosa pine, (2) more open conditions with larger trees, and (3) fire as a functioning component of the system. The study was designed to evaluate combinations of these three factors.

The AMA is located at 41.5 N latitude and 121.9 W longitude. The elevational range for the study site is 1,480 to 1,780 m (4,860 to 5,840 ft). The forest type (Eyre 1980) is predominantly Interior Ponderosa Pine (Society of American Foresters Type 237). Slopes are gentle, generally with a northwest aspect. Soils in the study area are sandy loams or loams derived from volcanic ash. A 20 to 36 cm (8 to 14 in) pumice overburden is common in the area. Site productivity is difficult to estimate in this area because current site quality trees are from two separate age cohorts, and many have not been truly free-to-grow. Based on the second-generation stand (trees with a breast height age < 70 years) site index (Barrett 1978) is 37 m (120 ft) at a base age of 100. Converted to a base age of 50 years, site index is 25 m (82 ft). This converts to a Forest Service Region 5 site class of 3.

In 1996, a sample of 20 stands in the area was selected to evaluate stand structure, species composition, and appropriateness for inclusion in the study (*table 1*). This represents pre-treatment conditions for stands within the study area. Units with recent sanitation and salvage entries tended to be more open than those without recent treatment history. Reineke's (1933) Stand Density Index (SDI) exceeded 570 (230 trees ac^{-1}), the zone of imminent mortality reported by Oliver (1995), in over half of these stands.

Table 1—*Summaries of pre-treatment quadratic mean diameter (QMD), basal area (BA), stand density index (SDI), stem density (N), and percentage of basal area in pine for stands of the Goosenest Adaptive Management Area. Units are metric with English equivalents in parentheses.*

	QMD	BA	SDI	N	Pine BA
	cm (in)	**$m^2\ ha^{-1}$ ($ft^2\ ac^{-1}$)**	**trees ha^{-1} (trees ac^{-1})**	**trees ha^{-1} (trees ac^{-1})**	**percent**
Minimum	24.6 (9.7)	26.6 (116)	474 (192)	217 (88)	15
1st Quartile	28.2 (11.1)	30.3 (132)	523 (212)	385 (156)	31
Median	29.0 (11.4)	37.0 (161)	689 (279)	568 (230)	43
3rd Quartile	39.4 (15.5)	42.9 (187)	822 (333)	778 (315)	60
Maximum	41.1 (16.2)	58.3 (254)	1084 (439)	902 (365)	73

There were four treatments: Pine Emphasis, Pine Emphasis with Fire, Large Tree, and a Control treatment. Each treatment was replicated five times in a completely randomized design (*fig. 1*). Each treatment unit was 40 ha (100 ac), with an additional buffer of approximately 100 m (328 ft). This experimental unit size was considered to be sufficient to encompass the range of small mammals and passerine birds (although this aspect of the study is not presented here). The number of replicates and variety of treatments was restricted by our ability to locate units of sufficient size with fairly uniform conditions.

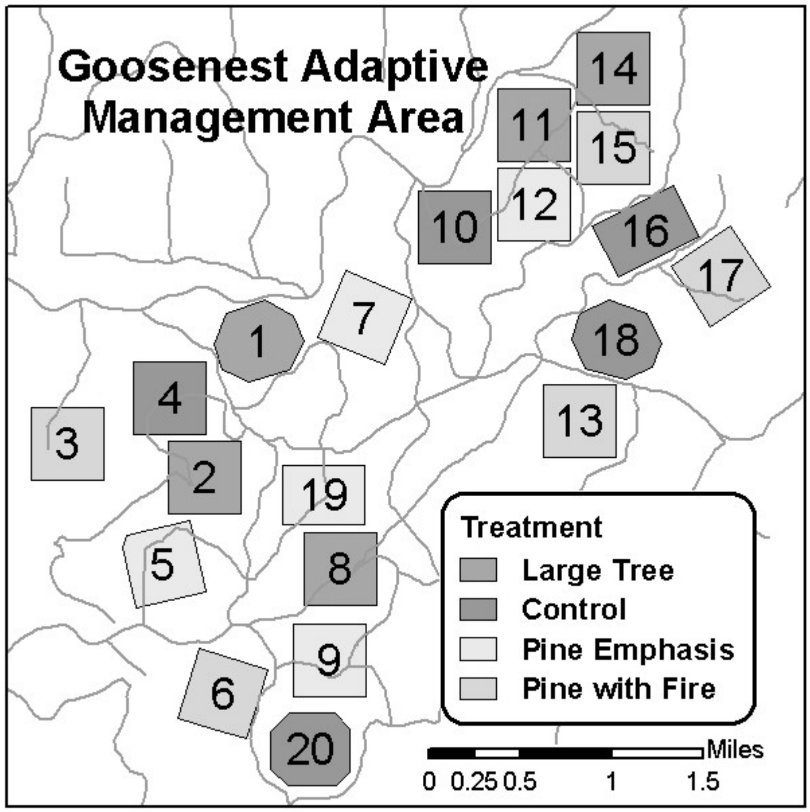

Figure 1—Map of the treatments at the Goosenest Adaptive Management Area.

The Pine Emphasis treatment was intended to accelerate growth of trees and modify species distribution by moving stands toward ponderosa pine dominance. The prescription called for a thinning from below with required retention of all dominant and co-dominant ponderosa pine and sugar pine, regardless of spacing (Ritchie 2005). Spacing for fir and intermediate or suppressed pine was determined by tree size with larger leave trees having a greater spacing than smaller trees. Because of the "must leave" requirement for ponderosa pine and sugar pine dominant and co-dominant trees, the resulting spacing was not uniform. Small aggregates of closely spaced trees were left scattered through the stand. Because artificial regeneration was the only effective means for changing species composition in areas with very dense white fir, small openings, totaling 15 percent of the area, were created in each unit and planted with ponderosa pine seedlings. The openings were deep-tilled to penetrate the pumice overburden and planted with 2-0 ponderosa pine seedlings.

The Pine Emphasis with Fire treatment began with the same thinning prescription and artificial regeneration as the Pine Emphasis. The thinning was then followed with application of prescribed fire. The application of prescribed fire took place after planting for some of the units, however fire did not carry through the plantations because the sub-soiling treatment buried surface fuels and exposed mineral soil.

The prescription called for stands to be burned repeatedly over time in a manner consistent with both the historic fire frequency, and fuel loadings sufficient to carry fire. Stands are to be re-evaluated periodically for the potential to carry fire in subsequent prescribed burns. A study is currently underway to document the historic fire frequency of the Goosenest AMA.

The Large Tree treatment was intended to address only the size distribution of trees in the stand. The prescription was a thinning from below with no regard for species. The intent was to create more large trees as quickly as possible by removing the smaller diameter trees. Since species distribution was not relevant to this treatment, there is no regeneration component. The prescription called for a size-dependent spacing guide (Ritchie 2005). The spacing varied from about 5 m to 9 m (16 to 30 ft), with larger leave trees being more widely spaced. This prescription tended to create a more uniform spacing than the Pine Emphasis treatment because there was no restriction on cutting dominant and co-dominant pine trees.

The Control treatment was consistent with custodial management. No thinning, prescribed burning, or salvage was conducted in the Controls. By comparing our treated units with Control units, we can quantify the impact of our prescriptions on a variety of treatment response variables.

All units have a 100 m (328 ft) grid of permanently monumented sample points; UTM coordinates for these points have an error of less than 15 cm (6 in). All data were spatially referenced to these grid points to facilitate integration of results from different disciplines (Oliver 2000).

Treatment Implementation

The Goosenest Ranger District completed the NEPA process, signed the Finding of No Significant Impact, and offered the timber for bid in 1997. Total revenue for the timber sale was $5.474 million. Scaling was done by weight; removals totaled 92,669 metric tons (green weight) of sawlogs and peelers, and 62,004 metric tons of chips from saplings, limbs, and tops.

To ensure conclusions would be based on the effects of the treatments, not on how the treatments were implemented, the control of all activities within the treatment units was important. To this end, the entire project was offered as one timber sale, knowing full well it would take at least three years to complete. Harvesting started in July 1998 and was completed in October 2000. In the first season, one complete replicate was thinned. In each of the two following years, two replicates were completed. All treatments were “leave-tree” marked, and all landings were located outside the treatment units. Two natural openings became the processing landings” Skid trails were pre-designated at approximately 60 m (200 ft) spacing. Operators were required to place (with feller-bunchers) or fall all trees to lead. Grapple skidders were restricted to the designated skid trails. Operations were authorized only when the soil was adequately drained to prevent compaction, and was neither frozen nor covered with snow.

First, the feller-bunchers cut and placed next to skid trails all trees from 10 cm to 45 cm (4 to 18 in). As the operation progressed across the unit, the skidders followed, dragging the bundles of trees to a “hot landing.” A heal-boom loader was used to sort the trees by size and species and load them onto a hay-rack (*fig. 2*). All limbs and tops accumulating at the landing were redistributed along skid trails by the grapple skidders. Finally, the fallers hand-felled trees greater than 45 cm (18 in) *DBH*. These trees were limbed, topped and skidded to the hot landing where they were loaded onto the hay-rack and hauled to the processing landing.

At the processing landings, trees were sorted by size and species. Ponderosa pine was processed for saw logs and white fir was processed as peelers. Trees larger than 20 cm (8 in) were limbed, topped, and cut to length by a stroke delimber. Saplings between 10 and 20 cm (4 and 8 in) were processed as clean chips for paper. Remaining saplings, tops and limbs were then processed for hog fuel.

After harvesting, the openings in the Pine Emphasis treatment units were deep-tilled and then planted.

Figure 2—Trees being transported from the hot landing to the processing site at the Goosenest Adaptive Management Area.

To minimize damage to fine roots and active cambium, fall burning was used in application of prescribed fire. The initial burns were conducted in October 2001 to all five of the Pine Emphasis with Fire units. Burning of each unit took up to three days. Although Forest Service crews typically use a strip burning technique, tree centered firing was widely used when possible (Weatherspoon and others 1989).

Vegetation Sampling Methods

Each treatment unit has approximately 36 grid points, at 100 m (328 ft) spacing, depending on orientation of unit boundaries. The number is slightly less than 40 due to restrictions on grid point establishment near the plot boundary. Every other grid point was selected for vegetation sampling, such that the sampled grid points are spaced at 141 m (463 ft) intervals.

The initial post-treatment vegetation sample was conducted in 2002, the season following completion of all harvesting and the initial application of prescribed fire. Typically such sampling would be done after the end of the growing season. However, due to the scale of this study, that was not possible. We may have to adjust growth to account for the period lengths between subsequent remeasurements (Flewelling and Peters 1997). The initial vegetation sampling and permanent plot establishment took two three-person crews the entire summer to complete.

At each sampled grid point, three nested fixed-area plots were established. Trees > 29.2 cm (11.5 in) breast-height diameter were sampled on a 0.81 ha (0.2 acre) plot centered on the grid point. Trees from 9.1 to 29.2 cm (3.6 to 11.5 in) diameter at breast height were sampled on a 0.020 ha (0.05 acre) plot, also centered on the grid point. Trees < 9.1 cm (3.6 in) diameter were tallied by 2.5 cm (1-inch) diameter classes on 0.004 ha (0.01 ac) plots.

Species, height, diameter, and height to crown base were recorded for each tree. We also recorded damage, with particular emphasis on damage related to treatment implementation. Damage was primarily bole scars from either skidding or fire scorch.

In order to evaluate growth on dominant (site-quality) trees, we sampled 36 site quality trees (Barrett 1978) on three treatment units. Increment cores were obtained from each tree and radial growth rates (periodic annual increment) were observed for the 2-yr period immediately before and after treatment. We conducted a paired t-test on pre and post treatment growth for each of the treatment units.

Coarse woody debris was sampled on a 100 m (328 ft) transect using the methods described by Brown (1978). Transects were centered on every grid point where trees were sampled. Material was identified as being either decay class 1 (recent material), class 2 (some decay but still structurally intact), or class 3 (advanced decay with no structure).

Results

The study was designed to evaluate responses over a 50-year time line. However, initial results can indicate something of the potential for effectiveness over the long-term as well as provide an indication of short-term changes in stand structure and habitat.

Stand Structure

The initial entry increased the proportion of pine for both Pine Emphasis and Large-Tree treatments, although the increase tended to be greater for the Pine Emphasis units. Large-Tree units showed a small increase in pine because a thin from below, with a dominance of fir in the understory, necessarily produces a reduction in fir (*fig. 3*). As the pine plantations develop, this change in proportion of pine should become more pronounced in the Pine Emphasis units.

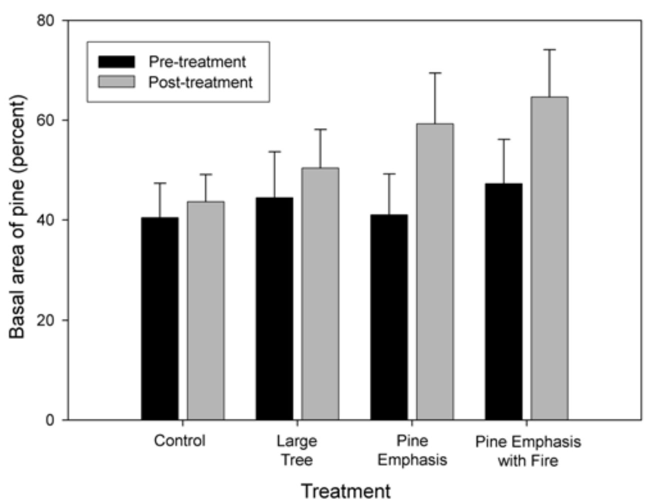

Figure 3—Change in species composition for four treatments in the Goosenest Adaptive Management Area (error bars = standard error).

A comparison of pre- and post-treatment diameter distributions, averaged across treatment units (*fig. 4*), shows that the skewed pre-treatment size distribution has been modified to a more symmetric distribution. There were very few trees above 60 cm (24 in) in diameter throughout the study (generally less than 15 trees per ha or 6 trees per acre). The Pine Emphasis units appear to have a higher proportion of pine, particularly in the middle diameter classes.

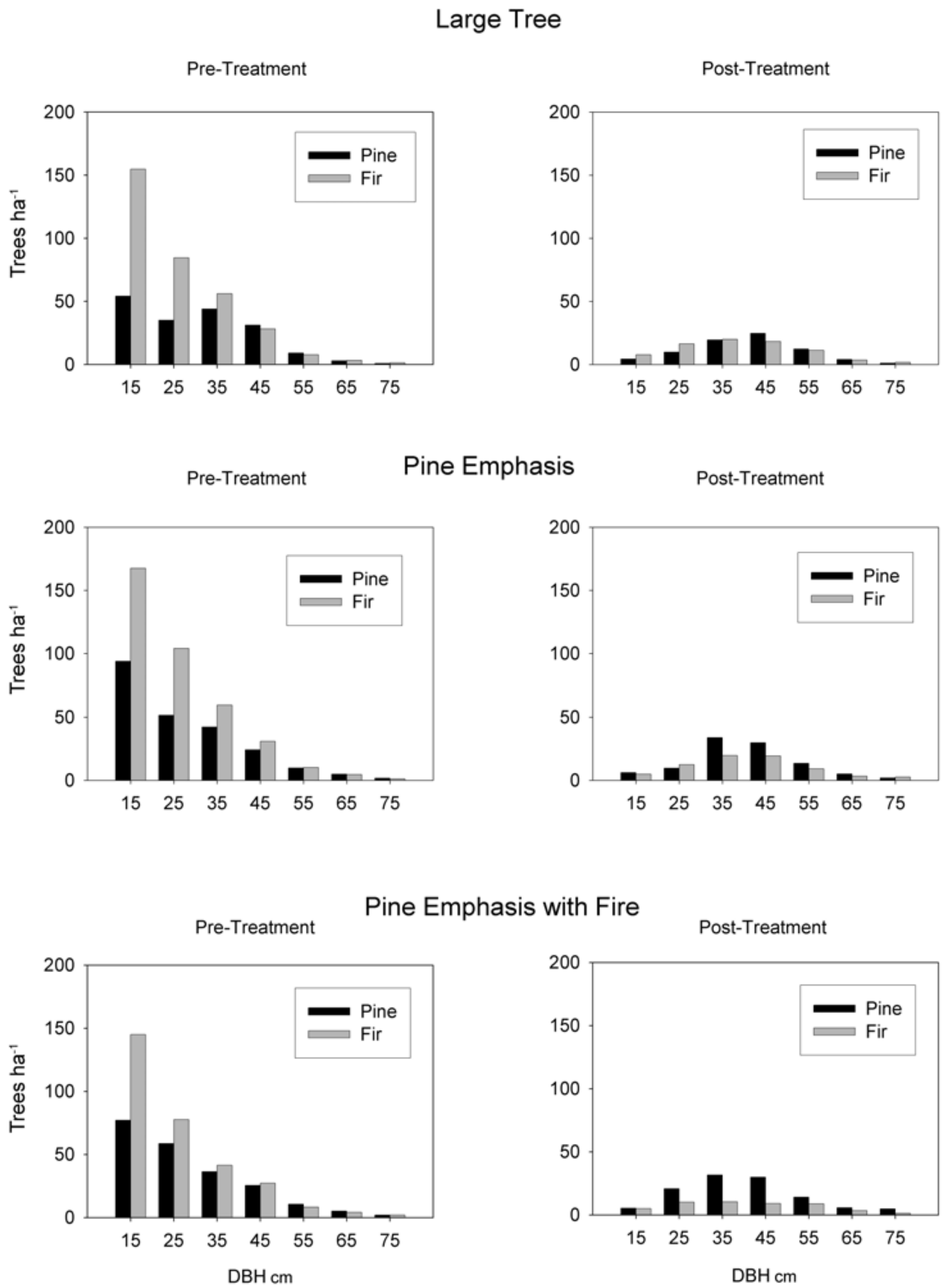

Figure 4 — Diameter distributions before (1996) and after (2002) treatment, averaged across experimental units, for the treatments (excluding Controls) in the Goosenest Adaptive Management Area.

Because treatments targeted the lower diameter classes, there is a pronounced "chainsaw effect" on *QMD*. *QMD* increased in treated units an average of 12.5 cm (4.9 in), ranging from 2.3 to 19.3 cm (0.9 to 7.6 in); *QMD* is substantially higher than in controls, as seen in the following tabulation.

Control	Large Tree	Pine Emphasis	Pine Emphasis with Fire
30.8 cm ± 1.5	43.5 cm ± 1.4	45.1 cm ± 1.6	43.6 cm ±1.6

The shape of the current diameter distribution in these stands is more consistent with hypothesized late-successional forest structure, where frequent low-intensity fires maintained a more open understory.

Number of large trees, defined as those > 60 cm (24 in) in diameter, varies across all treatments (*fig. 5*) from 5 to 35 trees ha^{-1} (2 to 14 trees ac^{-1}). Basal area was reduced an average of 29 percent for Pine Emphasis plots and 35 percent for Large Tree units. Stand density index (Reineke 1933) now ranges between 356 (143 ac^{-1}) and 453 (182 ac^{-1}) for the five Large Tree units and between 326 (131 ac^{-1}) and 572 (230 ac^{-1}) for the five Pine Emphasis Units.

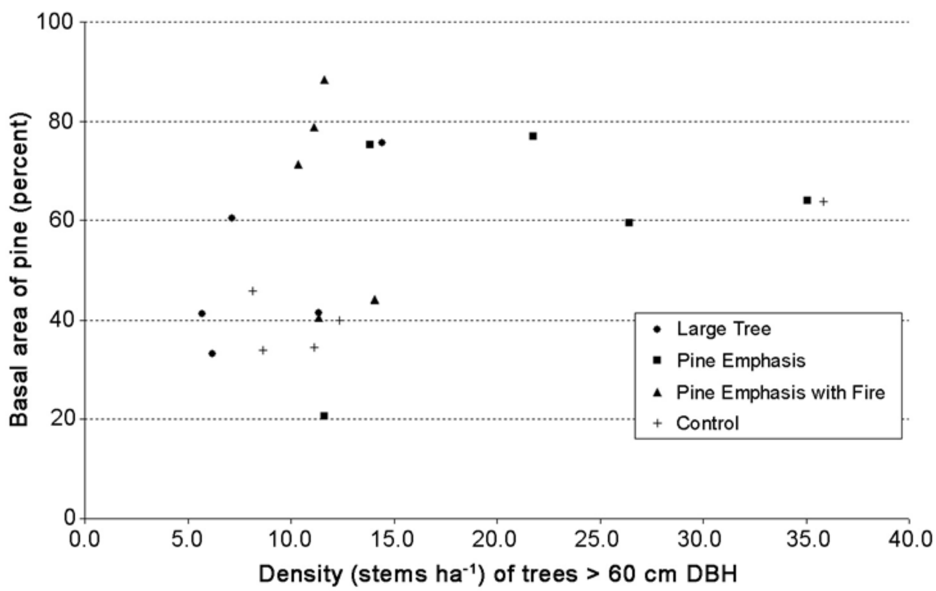

Figure 5 — Post-treatment (2002) proportion of pine, and number of large trees, defined as those > 60 cm (24 in) *DBH*, for treatment units in the Goosenest Adaptive Management Area.

Mortality and Damage

Initial mortality rates are low, indicating little damage to residual stands immediately after harvest and application of prescribed fire. Logging damage was also generally low (estimated below 6 percent) regardless of treatment and tree size. Damage was significantly less (P=0.001) among trees > 50 cm (20 in) in the Large Tree treatment when compared with the Pine Emphasis treatments (*fig.6*). This difference may be attributable to a more clumpy distribution of trees in the Pine Emphasis units.

Burn damage to residual trees in the units receiving prescribed fire was also low. Initial mortality among trees > 29 cm (11.5 in) diameter was less than 1 percent. Fire-related mortality among trees between 9 and 29 cm (3.5 and 11.5 in) *DBH* averaged 3.5 percent. This mortality rate is probably an underestimate because it only includes those trees killed within the first year after burning and does not reflect any secondary mortality that may occur over the next several years (Ryan and others 1988).

Initial Growth Response

Thinning in ponderosa pine generally increases growth on residual trees (Cochran and Barrett 1995, Cochran and Barrett 1999). A preliminary analysis of two-year thinning response, using a sample of trees from three different treatment units, revealed no significant change in tree growth in response to thinning. However, this may be due to high variability within treatments or because it may take several years for trees to build sufficient crown and roots to take advantage of the increase in available resources. The only evidence of accelerated growth was among small trees. Because most of the smaller trees were removed, there are very few residual trees less than 30 cm (12 in) in the treated units, so sample size was limited.

The treated plot with the greatest gain in diameter increment was the Pine Emphasis plot, with an increase of 14±12 percent (±90 percent confidence interval). In the Large Tree and Pine Emphasis with Fire Treatments we observed approximately 11±23 and 11±22 percent radial growth increase respectively. Note that the confidence interval includes zero for both the Large Tree and Pine Emphasis with Fire Treatments.

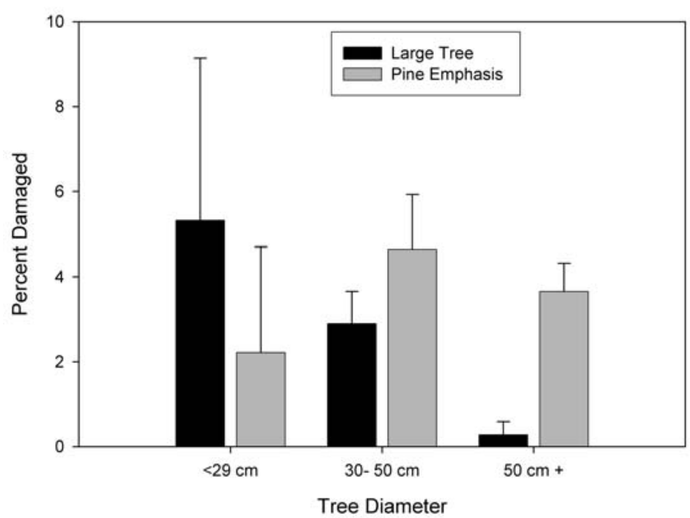

Figure 6 — Percentage of damaged trees by diameter class for Large Tree and Pine Emphasis Treatments (error bars = 1 standard error).

Woody Debris

The primary treatment impact on woody debris was from fire. There was no detectable difference between mechanical treatments. However a comparison of Pine Emphasis units and Pine Emphasis with Fire units showed a significant reduction in volume. Debris in a more advanced state of decay is substantially (73 percent by volume) reduced by fire (*P*=0.013). Material in a less advanced state of decay was reduced about 43 percent on average (*P*=0.120). Differences between burned (Pine Emphasis with Fire) and unburned (Pine Emphasis) was limited to smaller diameter class material (*table 2*).

Table 2 — *Post-treatment means (with standard error) for number of woody debris pieces ha^{-1} for Pine Emphasis (no burn) and Pine Emphasis with Fire (burn), by size class.*

	Length					
Diameter	**< 2m**		**2 – 4 m**		**4 – 6 m**	
	burn	no burn	burn	no burn	burn	no burn
< 25 cm	171 (16)	697 (186)	49 (8)	227 (65)	16 (6)	81 (20)
25-50 cm	75 (18)	175 (37)	48 (15)	81 (29)	14 (9)	34 (11)
50-75 cm	19 (4)	18 (4)	6 (3)	6 (3)	6 (3)	18 (8)
> 75 cm	3 (3)	6 (4)	3 (3)	3 (3)	0 (0)	1 (1)

Discussion

Observations of changes in growth rate are small at this point, primarily because it takes a few years for trees to develop leaves and roots to exploit the increased availability of resources. The growth rate increase observed for dominant trees appears to be less than that for stands with similar levels of growing stock observed by Cochran and Barrett (1999) who found that diameter growth increased by approximately 40 percent. However Cochran and Barrett (1999) had 30 years of observations. The results suggest that growth rates in the prescribed fire units are slightly less than those in Pine Emphasis units. This is consistent with research showing that diameter growth was suppressed, in the short term, following application of prescribed fire (Busse and others 2000).

Differences in diameter distribution are fairly subtle, except for the obvious difference between harvested and control units. Mortality processes initiated by fire and insects may take an extended period to significantly impact the dynamics of these stands. The expected distribution of large trees in late successional pine stands is difficult to ascertain. One of the few un-disturbed sites left in California averaged 17 trees ha^{-1} in trees > 60 cm (7 trees ac^{-1} >24 in) *DBH*, with a *QMD* of 53 cm (21 in) (Beaver Creek Pinery, data on file PSW Research Station, Redding CA). Treated unit *QMD* ranges from 36 to 48 cm (14.0 to 18.7 in). Youngblood and others (2004) found *QMD* of 60 cm in (24 in) old-growth ponderosa pine stands and density of overstory trees ranging from 15 to 53 ha^{-1} (6 to 21 ac^{-1}). With current growth rates, it could take a decade or more to increase stand diameter another 10 cm (4 in).

As one would expect, there were no discernable trends with regard to the number of trees > 60 cm (24 in) in the 2002 post treatment data. If any treatment effect is observed, it may take decades to detect.

The snag retention in units with prescribed fire is not consistent with published guidelines that range from 2-10 snags ha^{-1} (5 to 25 ac^{-1})(Bunnell and others 2002; USDA and USDI 1994b; USDA 2004). Maintenance of snags with frequent low-intensity fires is difficult because fire-induced mortality is low while many existing snags are consumed.

The rate of consumption of down material by fire at this site suggests that, with frequent application of prescribed fire, there will be very little coarse woody debris present, particularly with regard to material in an advanced state of decay.

Mortality and damage resulting from thinning was kept at low levels by laying out all skid trails in advance, marking all leave trees, and closely supervising operators.

Acknowledgements

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