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# Heavy Thinning of Ponderosa Pine Stands: An Arizona Case Study

Peter F. Ffolliott, Malchus B. Baker, Jr., and Gerald J. Gottfried

# Abstract

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Growth and structural changes in a mosaic of even-aged ponderosa pine (*Pinus ponderosa*) stands were studied for 25 years to determine the long-term impacts of a heavy thinning treatment to a basal-area level of 25 $ft^2$/acre. Basal area and volume growth of these stands has increased since thinning and likely will continue to increase as the residual trees increase in size. Furthermore, future stand integrity should be maintained at relatively low-density levels. It is unlikely, however, that timber production could be sustained at this level. A more plausible scenario is to manage the watershed for other resource values available from ponderosa pine stands.

**Keywords:** thinning treatments, ponderosa pine, timber-stand improvement, stand integrity, basal-area levels

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*Cover photo: Beaver Creek Watershed 17 thinning treatment.*

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# Introduction

Although timber-stand improvement to obtain a more desirable growing stock of younger trees is often prescribed for trees below sawtimber-size, larger trees are also removed to achieve the desired density. One type of timber-stand improvement operation is thinning to remove surplus trees to attain a specified stand density. How much to thin depends on the number of trees, basal area, or volume desired in the residual stand.

Results from early thinning studies in Arizona's ponderosa pine forests indicated that the diameter growth of the residual trees was often greater in lightly stocked stands than in denser stands. Little or no increase in volume or basal area growth was expected in densely stocked stands (Krauch 1949, Pearson 1950, Gaines and Kotok 1954, Myers and Martin 1963). In these studies, relatively high posttreatment basal areas of 80 to 120 $ft^2$/acre and (in some cases) higher levels were specified. Therefore, the results did not provide all of the information necessary to prescribe the full range of growing stock levels anticipated in the future, especially in low-reserve densities.

A thinning study was initiated in even-aged ponderosa pine stands at Taylor Woods on the Fort Valley Experimental Forest, about 10 miles northwest of Flagstaff. The purpose of this study was to provide information on changes in stand structure following thinning to a wide range of residual growing stock levels (GSLs). A GSL value is a numerical index designating the square feet of basal area that residual stands have, or will have, when the average diameter at breast height (dbh) of the trees is 10 inches or more. GSLs evaluated at Taylor Woods were 30, 60, 80, 100, 120, and 180. GSL of 30 represents a reserve-density level lower than previously evaluated (Myers 1967).

Early predictions and 20-year results from Taylor Woods were available to help estimate the response of even-aged ponderosa pine stands to these thinning treatments (Schubert 1971, Ronco et al. 1985). These findings demonstrate that the ability of ponderosa pine stands to respond to a range of thinning treatments provides considerable flexibility for managers to select initial stand management strategies. However, information on the response of ponderosa pine stands to thinning to low basal-area levels is needed; especially for uneven-aged stands. It is important to know, for example, how the structure of uneven-aged stands changes after thinning to a minimum basal-area level below which a stand's integrity might be lost due to blowdown. Therefore, stand growth and structural changes have been studied over a 25-year posttreatment period to determine the impacts of heavy thinning to a basal-area level of 25 $ft^2$/acre to obtain this baseline information.

# Methods

## Study Area

The stands studied were located on a 298-acre watershed (Watershed 17) about 35 miles south of Flagstaff, Arizona. The area was within the cutover, uneven-aged ponderosa pine forests of the Colorado Plateau physiographic province above the Mogollon Rim. This watershed was established on the Coconino National Forest as part of the Beaver Creek Program. The Beaver Creek Program was an interdisciplinary research effort of the USDA Forest Service and their cooperators to evaluate the effects of vegetation management practices on water, timber, forage, and other multiple use values on ponderosa pine forest lands (Brown et al. 1974, Baker 1986). One of the management practices evaluated was heavy thinning of ponderosa pine stands. Water yield improvement, an original objective of the thinning treatment (Brown et al. 1974, Baker 1986), while significant for 10 posttreatment years (1970-1980), was not sustained. However, the effects of this treatment on residual stand structures is reported here.

The stands are representative of those found in the *Pinus ponderosa*/*Quercus gambelii* habitat type (Muldavin et al. 1996). Their site index, based on age at breast height of 100 years (Minor 1964), ranged from 42 to 75 ft. Nearly 85% of these stands occurred on Productivity Class 6 sites with a productivity potential of about 30 $ft^2$/acre/year. Scattered Gambel oak (*Quercus gambelii*) and alligator juniper (*Juniper deppeana*) trees intermingled with ponderosa pine before thinning.

The stands studied had been established on soils of volcanic basalt and cinder parent materials[1]. Elevations range from 6,900 to 7,300 ft. Slopes varied from 5% to 15% on terrain with a southwestwardly orientation. Annual precipitation is 20 to 25 inches, falling mostly in 2 seasons. During winter, 65% of the annual precipitation, both rain and snow, falls (Brown et al. 1974, Baker 1986). The second major precipitation season is summer, particularly from July through September.

[1] *Soils are classified as fine, smectitic Typic Argiborolls; clayey-skeletal, smectitic Mollic Eutroboralfs; clayey-skeletal, smectitic Lithic Eutroboralfs; and fine, smectitic Mollic Eutroboralfs.*

## Thinning Treatment

The thinning treatment was based on individual groups of ponderosa pine trees. All trees 25 inches dbh and larger in a group were cut. It was then decided which of 4 size classes would dominate the residual stand. Size classes (classified by 2-inch dbh intervals) were grouped into saplings (less than 4 inches dbh), poles (4 to 10 inches dbh), small sawtimber (12 to 18 inches dbh), and large sawtimber (20 inches dbh and larger). Dominance was based on which tree crowns occupied the greatest proportion of the stand.

Ponderosa pine trees in nondominant size classes were marked for cutting. However, in some instances, a tree larger or smaller than the designated dominant size class was retained, or a tree of better form and quality was occasionally cut to achieve the prescribed spacing.

With the exception of the above instances, trees in the dominant size class were then thinned to a basal-area level of 25 $ft^2$/acre. When this treatment was prescribed in 1969, silvculturalists in the region felt that the residual stands might not be able to sustain themselves because of the low posttreatment density. This posttreatment basal-area level was just above the initial thinning level on the GSL 30 plots at Taylor Woods (Schubert 1971, Ronco et al. 1986). The plots at Taylor Woods were all stocked by even-aged stands of the same size class following treatment, while posttreatment conditions on the Beaver Creek watershed were a mosaic (in appearance if not age) of even-aged stands each dominated by 1 of 4 prescribed size classes.

Poor risk trees and trees with heavy mistletoe infection or poor stem form were also cut if their removal did not significantly reduce the basal area of the ponderosa pine trees to less than the target level. All Gambel oak trees over 15 inches dbh were removed, with the exception of den trees, leaving an average residual basal area level of 5 $ft^2$/acre. All alligator juniper were cut regardless of their size. Slash and heavy fuels were machine-windrowed.

## Inventory Methods

Systematic sampling with multiple random starts (Shiue 1960, Ffolliott 1965) was the original inventory design placed on the watershed to inventory the changes in stand structure. Permanently established sampling points were located at regular intervals along a series of transect lines. These transect lines were oriented to maximize the variability in measurements on sampling points along the lines, while minimizing the variability between the lines. There were 4 random starts and 4 strata (replications) placed on the watershed.

When the sampling design was initially established in 1963, the interval between sampling points along the transect lines was 198 ft (3 chains), providing a total of 93 sample points. However, this interval was reduced in 1969 (before the thinning treatment was imposed) to double the number of sampling points and attain the sampling intensity necessary to adequately evaluate the effects of the thinning treatment on stand structure. It was decided that the latter sampling intensity was sufficient, and well enough distributed on the watershed, to consider each sample point as a primary sampling unit in a simple random sample.

Point sampling techniques (Husch et al. 1982, Avery and Burkhart 1994) with a basal area factor (BAF) of 25 were used to select tally trees. The dbh of all tally trees 7 inches and larger and the total height of a sub-sample of trees were measured to localize a standard volume table (Myers 1963) to estimate cubic-foot volumes.

The stocking of small (less than 1-foot tall) and large (1 to 4-1/2-ft tall) ponderosa pine seedlings was tallied on 0.005-acre sample plots centered over the 186 sample points as part of the inventories. A plot was classified as stocked if at least 1 seedling was tallied; otherwise, the plot was not stocked.

Six inventories of the ponderosa pine stands were made. The first 2 inventories (1963 and 1969) represented conditions before the thinning treatment was applied. Information from these 2 inventories provided a point-of-reference for posttreatment evaluations. A third inventory was conducted in 1970, the year after the treatment was completed, to determine the proximity of the actual thinning treatment to its prescription. Three posttreatment inventories were then made to measure the changes in stand structure 5, 10, and 25 years following the thinning treatment.

## Analysis

While estimates of growth are important to manage forest stands, too often it is viewed in isolation rather than as one of a number of factors potentially affecting changes in stand structure. A critical question to ask when considering changes in stand structure is, "What is the stand density, and how has it changed in time?" Silviculturally, the question often is, "What is the response of a stand to a treatment?" Growth usually initiates this question, but change in stand structure is often the answer (Teply 1985). The inventory data collected in this study were analyzed to answer this question.

One problem in estimating changes in stand structures from repeated inventories of forest stands based on point sampling is on-growth trees. On-growth trees are not included in one inventory but are included in a subsequent inventory because they grew enough to be tallied with an angle gauge (Chambers 1985). A change in density caused by a large on-growth tree in a tally often makes foresters uneasy because of the large variance in growth estimates.

A possible solution to this issue might be to re-calibrate the sample points for successive inventories (Beers and Miller 1964, Chambers 1985). This approach was used in this study. Therefore, the data collected in the 6 inventories were summarized to indicate stand conditions, including on-growth, at the different points in time. Stand densities were expressed in number of trees, basal area, and cubic-foot volume per acre. The density summaries are presented below in terms of averages, and corresponding 95% confidence limits, and frequency distributions (stand tables, stock tables, etc.) to analyze structural stand differences.

While studying the following results, consider that:

- the effect of the thinning treatment on saplings and smaller poles (4 to 6 inches dbh) is unknown because only trees 7 inches in dbh and larger were sampled in the inventories and
- the dominant size classes originally identified as a basis for marking trees to be removed was not adequately identified ex-post from the inventory data.

As a consequence, it was impossible to isolate and then contrast the effects of thinning on particular size classes. The results are a composite of all stands on the watershed studied.

Table 1. Means and 95% confidence limits for densities of ponderosa pine trees 7 inches and larger on Beaver Creek Watershed 17.

| Inventory date | Density measure: Number of trees (number/acre) | Basal area ($ft^2$/acre) | Volume ($ft^3$/acre) |
|---|---|---|---|
| **Pretreatment** | | | |
| 1963 | 104.6 ± 23.4 | 75.3 ± 12.9 | 1,365.5 ± 251.9 |
| 1969 | 104.4 ± 16.3 | 78.8 ± 9.2 | 1,461.1 ± 170.8 |
| **Posttreatment** | | | |
| 1970 | 20.2 ± 3.5 | 19.4 ± 2.5 | 408.8 ± 59.9 |
| 1974 | 27.5 ± 6.0 | 22.2 ± 2.7 | 451.7 ± 62.8 |
| 1978 | 26.1 ± 5.3 | 23.4 ± 2.8 | 468.2 ± 61.0 |
| 1995 | 26.9 ± 6.6 | 29.8 ± 3.1 | 641.9 ± 67.4 |

*a = 0.05*

# Results and Discussion

The thinning treatment resulted in a 75% reduction of the original 120 $ft^2$/acre, leaving a mosaic of even-aged groups of differing ages with an average basal area of 30 $ft^2$/acre (Brown et al. 1974, Baker 1986). Basal areas are totals for all species and all size classes. A proportional reduction in basal area occurred in ponderosa pine trees 7 inches dbh and larger; that is, a reduction in density from about 80 $ft^2$ of basal area/acre to nearly 20 $ft^2$/ acre (table 1). The posttreatment stands were dominated mostly by trees in the pole and small sawtimber-size classes. The effects of thinning on densities and stand structure, regeneration stocking, and residual stand integrity at the low-reserve density level are discussed below.

## Changes in Stand Densities

Changes in stand densities in the 6 years (1963 through 1969) leading up to and the 25 years (1970 through 1995) following the thinning treatment are shown in table 1. There was little change in the means for number of trees, basal area, and volume in the pretreatment years. The smaller confidence limits around the calculated means of the conditions in 1969 in comparison to 1963 reflect the doubling of the sampling points in the 1969 inventory.

Earlier studies in Arizona's ponderosa pine stands had shown that little or no increase in basal area and volume growth per acre can be expected as a result of most thinning treatments, but that individual trees were likely to grow faster once they were released (Pearson 1950, Gaines and Kotok 1954, Myers and Martin 1963). Similar trends were observed in the first 8 years following treatment (1970 through 1978) in this study. However, by the end of the 25-year posttreatment evaluation period, increases in basal area and volume growth per acre were significantly greater than comparable values for the initial posttreatment period. The number of trees per acre remained unchanged throughout the posttreatment period.

Increases in the periodic annual increments (PAIs) of basal area and volume at the end of 25 years, while statistically significant in relation to the initial posttreatment period, were relatively small. On a per acre basis, PAIs for square feet of basal area were 0.42 and for cubic feet of volume were 9.3 for the 25-year period. These increments were all smaller than those reported at Taylor Woods for the average of the GSL 30 plots after the first 10-year thinning cycle (Ronco et al. 1985). The larger PAIs at Taylor Woods are attributed partly to the site's higher potential for wood production. The site index (Minor 1964) average was 73, with a Productivity Class 6 site and a productivity potential of about 48 $ft^3$/acre/year. This was higher than the site index on the Beaver Creek watershed, which was 30 $ft^3$/year. Another factor contributing to the higher PAIs on the Taylor Woods plots was that the mostly sapling trees released by the original thinning treatments responded more vigorously to the reduction in density than the larger, predominantly pole and small sawtimber-sized trees retained in the stands on the Beaver Creek watershed. While both study areas were thinned to the same low-reserve density levels, in this study, as reported earlier (Gaines and Kotok 1954), smaller ponderosa pine trees grew faster than larger trees following their release by heavy thinning.

## Changes in Stand Structure

Arizona's cutover ponderosa pine forests, while typically uneven-aged in their overall structure, are generally a mosaic of even-aged stands (Pearson 1950, Cooper 1961, Schubert 1974). This was the pretreatment structure of the composite of stands on the Beaver Creek watershed, which was altered as a consequence of the thinning treatment.

Pretreatment and posttreatment inventories reflect changes in the structure of ponderosa pine stands comprised of trees 7 inches in dbh and larger. Stand structure based on dbh distributions (stand tables) before thinning exhibited features associated with uneven-aged characteristics such as the classical inverted J-shape of uneven-aged forest stands (figure 1a). However, in the 25-year posttreatment period, the dbh distribution changed into that generally observed in the early stages of converting uneven-aged stands to even-aged stands. It is anticipated that the dbh distribution will continue to become similar to even-aged stand structures.

Distributions of basal area (figure 1b) and volume per acre by dbh classes (figure 1c) (the latter being stock tables) also differed between pretreatment and posttreatment inventories. Again, these distributions illustrate uneven-aged structures of ponderosa pine stands, evolving into distributions reflecting the early stages of uneven-aged stands converting to even-aged stands. Additional thinnings would be required to complete this conversion process, however. Depending upon the initial structure of the uneven-aged stand to be converted, 2 or more thinning treatments are generally necessary to achieve the desired even-aged structure (Schubert 1974).

It is not surprising that the thinning treatment on the Beaver Creek watershed is encouraging a mosaic of even-aged stands. The original thinning prescription specified thinning to favor 1 of 4 size classes in the residual stands.

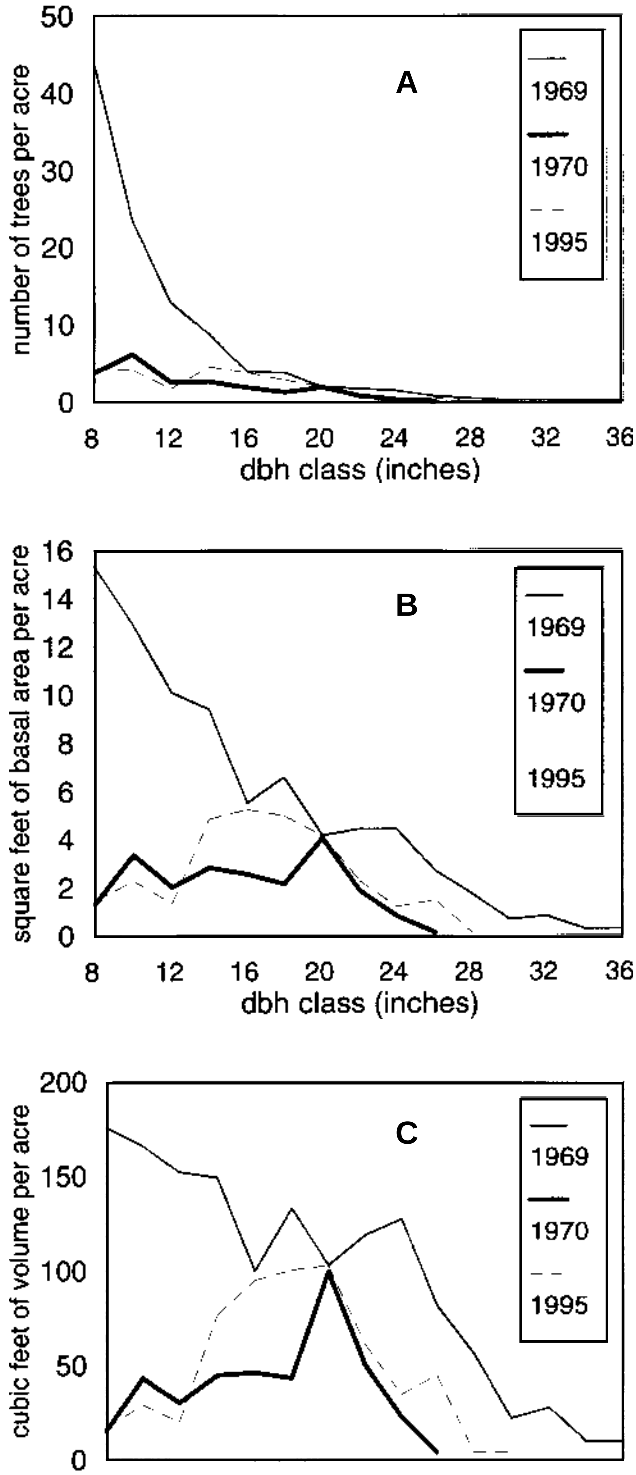


Figure 1. Distributions of: a) number of trees, b) basal area, and c) volume per acre for ponderosa pine trees 7 inches dbh and larger before (1969), immediately after (1970), and 25 years after (1995) the heavy thinning treatment on Beaver Creek Watershed 17.

Large sawtimber, the largest size-class considered, was found in a limited number of residual stands on the watershed in 1995. Two other size classes, poles and small sawtimber, were the predominant size classes in the posttreatment dbh distributions shown (figure 1a). The smallest size class (saplings) was not inventoried in this study and, therefore, was not included.

### Stocking of Regeneration

Stocking of regeneration reflects the general distribution of regeneration over the watershed. Immediately before thinning, 56% of 186 0.005-acre sample plots were stocked with either small or large ponderosa pine seedlings. The regeneration distributed randomly. These stocking conditions were similar to others in the cutover ponderosa pine stands on the Beaver Creek watersheds (Ffolliott and Gottfried 1991). However, stocking on the Beaver Creek watershed studied was severely reduced due to the thinning treatment. Less than 2% of the sample plots were stocked with seedlings immediately after completion of treatment activities. The loss in stocking was attributed to felling and skidding the trees marked for thinning and pushing the slash and heavy fuels into windrows by tractor and blade.

The loss in regeneration was only temporary; nearly 40% of the sample plots were restocked with one or more small seedlings by 1974. The scarified soil surface provided a favorable seedbed for germination of seeds dispersed in 2 seed years (1970, 1973), which contributed to the increase in posttreatment stocking. Posttreatment stocking remained at this level in the 1978 and 1995 inventories. This stocking level was almost 15% higher than that observed 23 years after a total clearcutting treatment on another Beaver Creek watershed (Ffolliott and Gottfried 1991). The rate at which seedlings became established after the thinning treatment, and the rate at which these seedlings grew into the sapling and larger size classes are unknown.

### Integrity of Residual Stands

In 1969, silviculturalists thought that the integrity of the residual stands could be lost because of the low-reserve density prescribed by the thinning treatment. However, this generally did not happen, although a blowdown in the early spring of 1975 caused a minimal loss of stand volume. This loss occurred following a wet winter, when a spring wind storm uprooted a few isolated, mostly sawtimber-sized trees on a limited area of the watershed. A salvage harvest to recover the merchantable blowdown volume removed approximately 2,500 $ft^3$ from the watershed shortly after the storm. The loss of trees from this blowdown event, the only loss of its kind in the 25-year-posttreatment period of the study, was not a factor relative to maintaining the integrity of the residual stands. Posttreatment stocking of regeneration, while not back to pretreatment levels by 1995, appeared sufficient to ensure the growth of trees into sapling and larger dbh classes necessary to sustain the stands at the prescribed low stocking levels in the absence of drought, fire, or other catastrophic events.

## Conclusions

The integrity of residual ponderosa pine stands on the Beaver Creek watershed studied should be maintained into the future. Furthermore, the PAIs should increase as the residual trees increase in basal area and volume. A question that a manager might ask at this time is, "What should the future strategy be relative to managing these stands?"

Researchers responsible for planning the thinning treatment felt that the treatment could be repeated every 20 years to sustain "good timber production" at the prescribed low stocking levels (Brown et al. 1974). However, the emphasis of forest management in the region has changed since the thinning treatment was imposed in 1970 from timber production to a holistic perspective of natural resources management.

Current management strategies for the watershed should consider other multiple-use values that can be obtained from ponderosa pine forest. Increased forage production relative to pretreatment conditions that are attributed to the reduction in forest overstory densities (Bojorquez Tapia et al. 1990) is likely. Habitats for many wildlife species would benefit from thinning, largely because of the increase in forage with retainment of sufficient protective cover (Larson et al. 1986, Ffolliott 1997). Habitats for some wildlife may be enhanced by the mast provided by the Gambel oak trees not included in the thinning treatment and by the increased oak sprouts (browse) resulting from the treatment (Reynolds et al. 1970).

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