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# STEM FORM CHANGES IN UPLAND OAKS AFTER THINNING


**by Donald E. Hilt**

**and Martin E. Dale**



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NORTHEASTERN FOREST EXPERIMENT STATION
370 REED ROAD, BROOMALL, PA. 19008

## The Authors

DONALD E. HILT received his bachelor's degree in forestry from Iowa State University in 1969, and a master of science degree in forestry from Oregon State University in 1975. He joined the Northeastern Forest Experiment Station in 1975 and worked as a statistician in the biometrics group in Upper Darby, Pennsylvania. He transferred to Delaware, Ohio, in 1976 where he is now a research forester specializing in studies of growth and yield of managed upland oaks.

MARTIN E. DALE joined the Forest Service in 1957 and specialized in forest management and silviculture research at Berea, Kentucky. In 1973, he received a Ph.D. degree in forest biometry from Iowa State University, and since 1970 has been assigned to the Northeastern Forest Experiment Station's research unit on timber measurement and management planning at Delaware, Ohio. Currently he is specializing in studies of growth and yield of managed upland oak.

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## Abstract

Results of two independent studies were analyzed to determine whether residual stocking after thinning had any effect on change in stem form of upland oak. One study is based on 15 years' change in Girard Form Class after thinning of an 80-year-old white oak stand in eastern Kentucky. The other, 12-year changes in Girard Form Class and breast-height form factor based on Barr and Stroud Dendrometer measurements in 35-year-old thinned upland oak stands in Ohio, Kentucky, and Missouri. Sample trees in both studies were in the dominant and codominant crown classes. Neither study showed any significant differences in stem form changes that could be related to residual stocking. The change in stem form, however, was significantly correlated with the initial form for all stocking levels. Trees with the best form were more likely to deteriorate in form while the poorly formed trees were most likely to improve, regardless of the residual stocking level.

# INTRODUCTION

FOR MANY YEARS foresters have been concerned that heavy thinning may cause the stem form of residual trees to deteriorate, and consequently volume equations or tables that are usually based on uncut stands may overestimate volume growth in managed stands. If stem form changes were severe, a modification of the volume table or equation would be needed to predict stem volume and volume growth accurately.

In a comprehensive review of studies on stem form development, Larson (1963) points out that one of the most controversial aspects of the problem is the degree to which thinning alters stem form. Several authors have found that releasing a well-formed stand-grown tree results in a free-growing tree with more taper (Larson 1963). Other authors have reported that thinning causes the residual trees to grow toward a common form class (Meyer 1931, Behre 1932). Well-formed trees are reported to deteriorate in form after thinning, while the poorer formed trees improve in form.

The objective of our studies was to determine whether the residual stocking level after thinning had any effect on stem form change in upland oaks.

# THE STUDIES

The plots used in both studies were part of a larger regional study of stand density designed to develop growth and yield relations for thinned upland oak stands. All plots were originally well-stocked even-aged stands with no evidence of recent disturbances such as cutting, fire, or grazing. The site quality is typical for much of the upland region, ranging between site index 60 and 75 for black oak.

The first study was established in 80-year-old white oak stands on the Baldrock Experimental Forest in southeastern Kentucky. Sixteen 1-acre plots were thinned initially in 1959 so that the residual stand ranged from about 24 to 77 percent stocking, based on Gingrich's (1967) tree-area-ratio equation. Girard Form Class was determined for a sample of 368 dominant or codominant white oak *(Quercus alba* L.) in 1959 and 1974 (Table 1). Stem diameters at 4.5 ft and 17.3 ft were measured outside bark with a diameter tape. The exact point of measurement was permanently marked so that later measurements would be taken at the same place. A ladder was used so that the measurements of upper stem diameter and double bark thickness (made with a Swedish bark gauge) could be accurately read. Some

**Table 1.—Summary statistics for two stem form studies of upland oaks**

| Stocking level (percent) | Number of trees | Average dbh, outside bark (inches) | | Average height (feet) | | Average age (years) | | Average site index |
|---|---|---|---|---|---|---|---|---|
| | | BALDROCK STUDY | | | | | | |
| | | *1959* | *1974* | *1959* | *1974* | *1959* | *1974* | |
| <50 | 177 | 10.4 | 13.1 | 74.0 | 82.3 | 80 | 95 | 63 |
| 50-75 | 142 | 10.5 | 12.5 | 75.6 | 87.2 | 72 | 87 | 64 |
| 75+ (control) | 49 | 10.5 | 12.6 | 76.7 | 88.4 | 80 | 95 | 66 |
| All trees | 368 | 10.4 | 12.8 | 75.0 | 85.0 | 77 | 92 | 64 |
| | | BARR AND STROUD STUDY | | | | | | |
| | | *1964* | *1976* | *1964* | *1976* | *1964* | *1976* | |
| <50 | 33 | 6.9 | 9.6 | 52.1 | 63.0 | 35 | 47 | 69 |
| 50-75 | 45 | 6.9 | 8.8 | 49.9 | 61.3 | 34 | 46 | 71 |
| 75+ (control) | 34 | 7.0 | 8.7 | 53.2 | 64.6 | 37 | 49 | 69 |
| All trees | 112 | 6.9 | 9.0 | 51.5 | 62.8 | 35 | 47 | 70 |

study plots were thinned again in 1970, but these were all very light cuts. This first study will be referred to as the Baldrock study.

The second study used several upland oak species with an average age of about 35 years. The plots were located in three widely separated geographical areas: southeastern Ohio, east-central Kentucky, and south-central Missouri. We refer to this as the Barr and Stroud study simply because all measurements of upper stem diameter were made with the Barr and Stroud Dendrometer in 1964 and 1976. Trees were sampled on 34 half-acre plots that had been thinned in 1961 or 1962 to various stocking levels so that the residual stand ranged between 27 and 93 percent stocking. Some of the higher stocked plots were never thinned, and some plots received a second light thinning between 1968 and 1971.

The results are based on 112 dominant or codominant trees: 41 white oak, 51 black oak (*Q. velutina* Lam.), 14 scarlet oak (*Q. coccinea* Muenchh.), and 6 chestnut oak (*Q. prinus* L.) (Table 1). Dendrometer readings were taken at 6 to 11 points along the bole of each tree, and with the appropriate bark-thickness factor, an inside bark diameter was assigned to each measurement point. Then, by a linear interpolation procedure, diameters were computed for the specific points needed to calculate the Girard Form Class and the breast-height form factor for each stem.

For statistical analyses, data for each study were separated into three stocking levels based on the average percent stocking of the plots over the measurement interval: less than 50 percent, 50 to 75 percent, and greater than 75 percent. Data from plots that averaged greater than 75 percent stocking essentially represent a control treatment (no thinning to very light thinning). Table 1 shows the number of sample trees and the initial and final average dbh and total height by stocking levels for both studies. The initial average dbh for the three stocking levels was about 10.4 inches for the older trees in the Baldrock study and about 6.9 inches for the younger trees in the Barr and Stroud study.

# MEASURE OF STEM FORM

In its narrowest sense, stem form refers to the shape of the stem. It is defined by the Society of American Foresters (Ford-Robertson 1971) to mean the degree and mode of taper in the stem, most often expressed by a numerical value such as form quotient or form factor. In this paper we use the *Girard Form Class* and the *breast-height form factor* to express stem form. Girard Form Class is the percentage ratio of diameter inside bark at 17.3 ft (5.27 m) to dbh outside bark. The breast-height form factor is defined as the inside bark volume of the stem from dbh to total height, divided by the volume of a cylinder whose base is dbh inside bark, and length is the distance from dbh to total height.

# ANALYSIS AND RESULTS

The average changes in Girard Form Class and breast-height form factor are shown in Table 2. There was an increase in Girard Form Class for all stocking levels in both studies. Form factor, however, decreased on the two lower stocking levels. To help explain this apparent contradiction, we used the data collected on upper stem diameter from the Barr and Stroud study to develop Figures 1a-1c. These figures show the percent of height above dbh plotted over the ratio of diameter inside bark to dbh inside bark for each of the three stocking categories. These figures reveal that *on the average* growth was concentrated on the basal part of the stem. The concentration of growth continued up the stem at least as far as 17.3 ft (5.27 m). Stem growth at 17.3 ft increased relative to dbh inside bark, hence the increase in Girard Form Class. Figures 1a-1c also reveal that upper stem growth was reduced relative to dbh inside bark, hence a reduction in form factor. These figures may explain some of the differences reported in the

**Table 2.—Statistics for Girard Form Class and breast-height form factor for two studies of upland oaks, by stocking level**

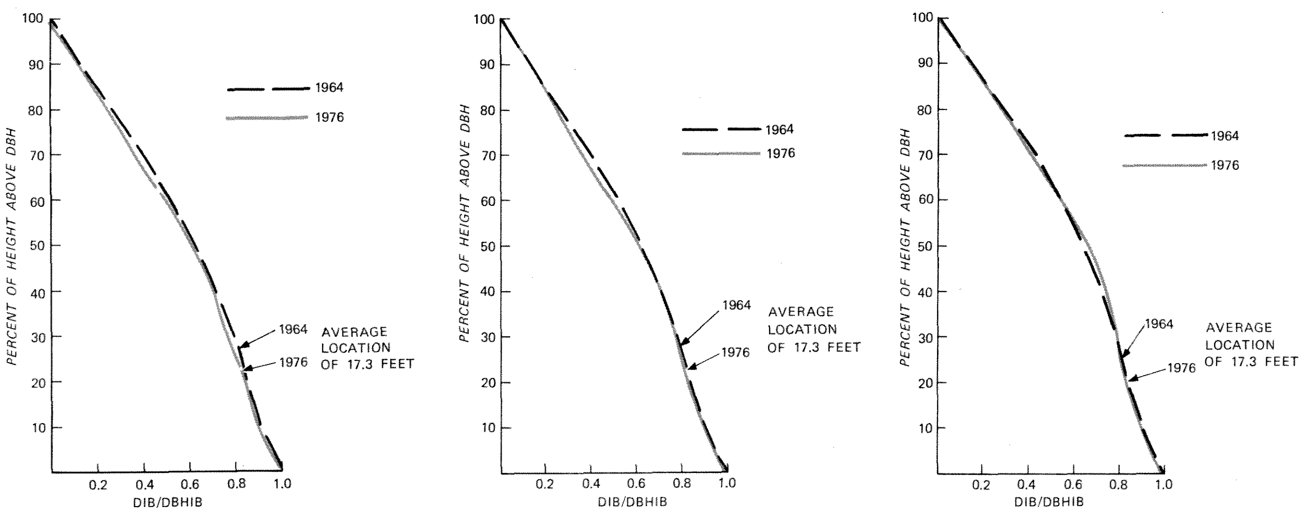
| Stocking level (percent) | Number of trees | Average initial form | Average change in form | Correlation between form change and initial form |
|---|---|---|---|---|
| | | BALDROCK STUDY—Girard Form Class | | |
| <50 | 177 | 77.14 | +1.22** | −0.178* |
| 50-75 | 142 | 75.91 | +1.50** | −0.306** |
| 75+ (control) | 49 | 77.40 | +0.67 | −0.365** |
| All trees | 368 | 76.70 | +1.25** | −0.253** |
| | | BARR AND STROUD STUDY—Girard Form Class | | |
| <50 | 33 | 73.69 | +1.10 | −0.603** |
| 50-75 | 45 | 71.20 | +3.55** | −0.605** |
| 75+ (control) | 34 | 72.42 | +3.00** | −0.643** |
| All trees | 112 | 72.30 | +2.66** | −0.609** |
| | | BARR AND STROUD STUDY—Breast-Height Form Factor | | |
| <50 | 33 | 0.374 | −0.015* | −0.391* |
| 50-75 | 45 | 0.368 | −0.005 | −0.437** |
| 75+ (control) | 34 | 0.373 | +0.004 | −0.430* |
| All trees | 112 | 0.371 | −0.005 | −0.408** |

**Significant at 0.01 level.
*Significant at 0.05 level.

**Figure 1a.—Diameter inside bark ratios, stocking less than 50 percent. Barr and Stroud study. Based on 33 stems.**

**Figure 1b.—Diameter inside bark ratios, stocking 50 to 75 percent. Barr and Stroud study. Based on 45 stems.**

**Figure 1c.—Diameter inside bark ratios, stocking greater than 75 percent. Barr and Stroud study. Based on 34 stems.**



literature on the effect of stocking on stem form. Analyses on the same set of data using different expressions of stem form can result in contradictory conclusions. Girard Form Class is an excellent measure of form for the butt log, which is often of primary interest, but form factor appears to be a better expression for the entire main stem.

Correlation analyses and scatter plots revealed that variations in site, age, dbh, and species within a study did not have much influence on stem form changes. Changes in stem form, however, were significantly correlated with initial stem form (Table 2). Trees with a high initial form class or form factor deteriorated in form, or at least did not improve as much as trees with a low initial form. Regressions of change in stem form on initial stem form were fitted by least squares for all trees in each stocking level and plotted over the range of the data to graphically illustrate this relationship (Figs. 2a-2c). This result is consistent with the findings of Meyer (1931) and Behre (1932).

**Figure 2b.—Relationship between change in Girard Form Class and initial Girard Form Class, by stocking levels. Barr and Stroud study.**

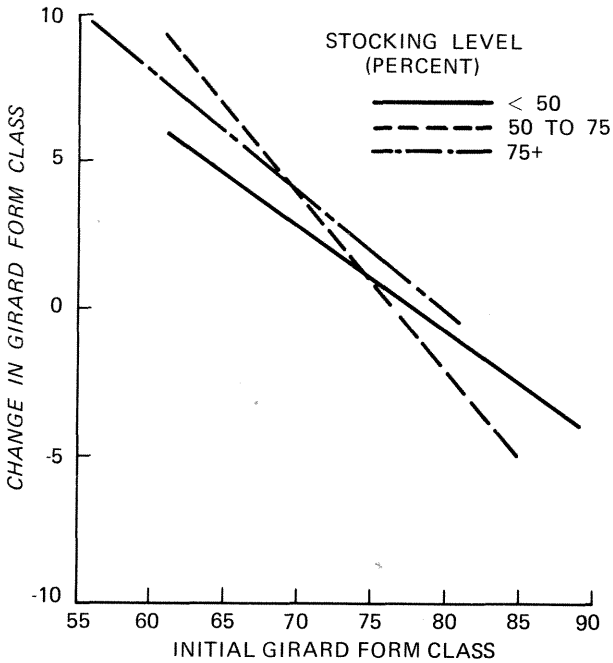



**Figure 2a.—Relationship between change in Girard Form Class and initial Girard Form Class, by stocking levels. Baldrock study.**

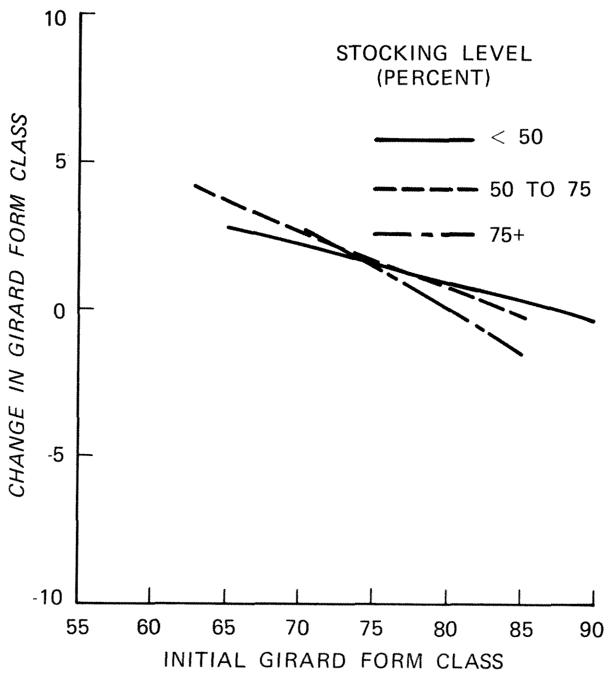
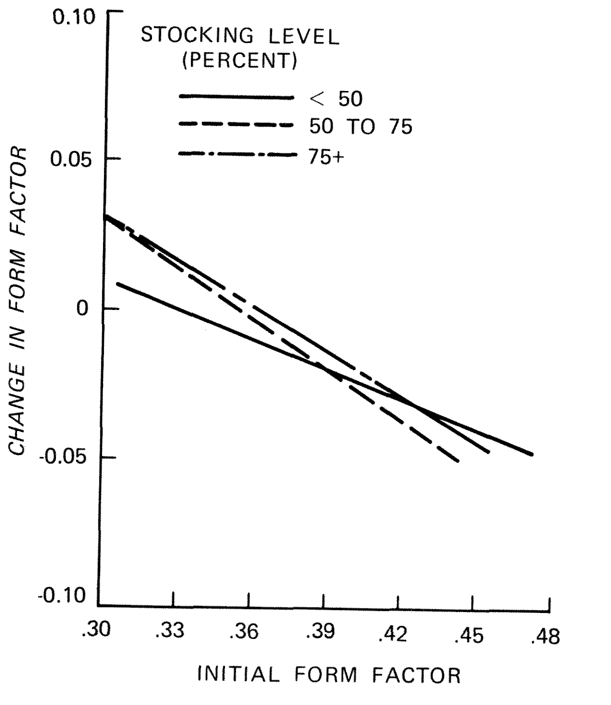



**Figure 2c.—Relationship between change in breast-height form factor and initial form factor, by stocking levels. Barr and Stroud study.**



The change in the average stem form for a stand, therefore, is dependent on the form of the residual trees after thinning. If only those trees with lower than average form are left after thinning, one would expect an improvement in stem form. If only those trees with better than average form remain after thinning, one would expect a deterioration in stem form, or at least not as marked an improvement (see Fig. 2a). It is important to note that the relationship between stem form changes and initial stem form holds for *all* stocking levels, even the 75+ percent level. Therefore, the relationship cannot be attributed to thinning alone.

The relationship between stem form changes and initial form illustrated in Figures 2a-2c was consistently the same within individual stocking plots. It was also consistent between plots when the range in initial form was not the same for all plots. Since statistical tests revealed no significant differences between the slopes of the within-plot regression lines for a given stocking level, we used the individual trees within a stocking level as observations to construct the regression lines in Figures 2a-2c.

Statistical tests to determine the equality of the regression lines in Figures 2a-2c were performed for each study (Table 3). As expected, initial form accounted for a significant part of the variation in the change in form. The hypothesis of equal slopes between stocking levels could not be rejected in any of the three analyses. The overall F test for differences in the intercepts was not significant at the 0.05 level for any of the three analyses. We conclude that the regression lines are the same for all three stocking levels. Thinning did not have a statistically significant effect on stem form changes.

# EFFECT OF FORM ON VOLUME ESTIMATION

The effect of stem form on volume estimation can be considerable. It is well known that the difference between one Girard Form Class and another amounts to approximately 3 percent in terms of merchantable volume (Avery 1967). When Girard Form Class volume tables

**Table 3.—Analysis of covariance tables for stem form changes in two studies of upland oaks**

| Source of variance | Degrees of freedom | Mean square | F value |
|---|---|---|---|
| BALDROCK STUDY—Girard Form Class | | | |
| Difference for testing common intercepts | 2 | 6.3628 | 0.9391$^{NS}$ |
| Initial form | 1 | 156.1538 | 23.0474** |
| Error | 364 | 6.7753 | |
| Difference for testing common slopes | 2 | 5.9625 | 0.8795$^{NS}$ |
| Error | 362 | 6.7798 | |
| BARR AND STROUD STUDY—Girard Form Class | | | |
| Difference for testing common intercepts | 2 | 20.3763 | 2.1069$^{NS}$ |
| Initial form | 1 | 560.6309 | 57.9697** |
| Error | 108 | 9.6711 | |
| Difference for testing common slopes | 2 | 21.5906 | 2.2856$^{NS}$ |
| Error | 106 | 9.4462 | |
| BARR AND STROUD STUDY—Breast-Height Form Factor | | | |
| Difference for testing common intercepts | 2 | 0.0031 | 2.4756$^{NS}$ |
| Initial form | 1 | 0.2800 | 22.5652** |
| Error | 108 | 0.0012 | |
| Difference for testing common slopes | 2 | 0.0006 | 0.4958$^{NS}$ |
| Error | 106 | 0.0013 | |

NS—Not significant at the 0.05 level.
**Significant at the 0.01 level.

are used, the form class is determined and the appropriate volume table is then selected. This procedure acts as a check against using the wrong volume table if stem form changes. Girard Form Class tables, however, are seldom used for upland oaks.

The effect of stem form on volumes estimated from empirically constructed volume tables is less distinct. Actual cubic foot volumes, inside bark, were calculated from the dendrometer readings in the Barr and Stroud study for the 112 trees. Tabular cubic foot volumes, inside bark, were read from Schnur's (1937) volume tables. Ratios of actual volumes divided by tabular volumes were regressed on form factor and plotted in Figure 3. An increase of 0.05 in form factor resulted in a 7 percent increase in the actual to tabular volume in 1964, and a 12 percent increase in the actual to tabular volume in 1976. The difference between the rates of increase can be attributed to the fact that the form factor is not constant over all diameter and height categories in Schnur's volume tables. The effect of form on volume estimation is indeed striking.

We also investigated the capability of Schnur's volume tables to consistently estimate the actual cubic foot volumes of trees before thinning (in this case, immediately after thinning) and 14 to 15 years after thinning. The character of the sample trees may not be representative of the volume table under consideration, but, as Meyer (1931) points out, it is the relative change, or progressive differences in the ratio of actual to tabular volume that is of primary interest. The mean ratios of actual to tabular volumes in 1964 and 1976 are listed by stocking levels in Table 4 for the Barr and Stroud study. The character of the sample trees in this case was representative of Schnur's volume tables because the mean of ratios was near the value one. The largest change in the mean ratios was −0.03. The change in ratios for the 75+ percent stocking level was only −0.01. None of the changes was significant at the 0.05 level. We conclude that a modification of Schnur's volume tables is not necessary when they are used for estimating cubic volumes of trees in thinned stands.

Even if the change in average form factor

**Figure 3.—Effect of stem form on volume estimation. Barr and Stroud study. Based on 112 stems, and Schnur's volume tables.**

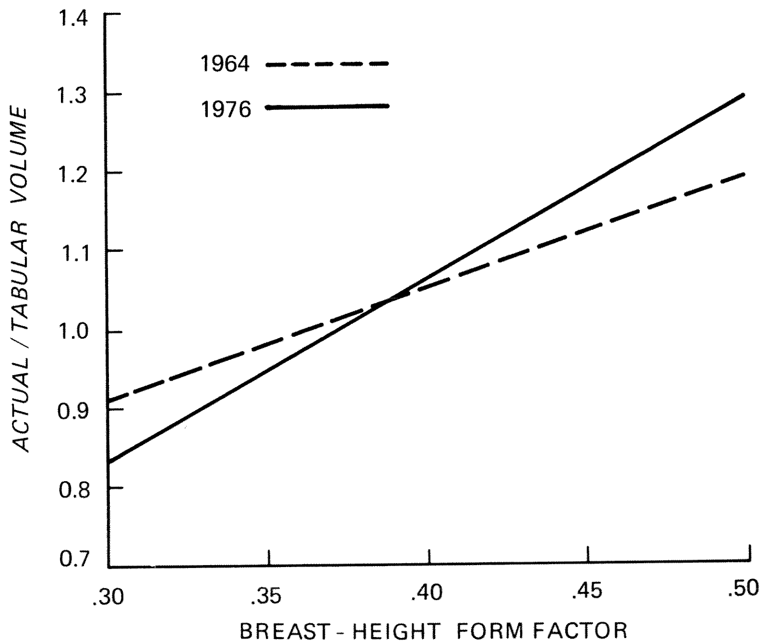


**Table 4.—Mean ratios of actual to tabular volumes for Barr and Stroud study of upland oaks, by stocking level**

| Stocking level (percent) | 1964 | 1976 | Change |
|---|---|---|---|
| <50 | 1.02 | 0.99 | $-0.03^{NS}$ |
| 50-75 | 0.99 | 0.96 | $-0.03^{NS}$ |
| 75+ | 1.02 | 1.01 | $-0.01^{NS}$ |
| All trees | 1.01 | 0.98 | $-0.03^{NS}$ |

NS—Not significant at the 0.05 level.

after thinning is highly significant, like the −0.015 average change for the lowest stocking level in the Barr and Stroud study, the volume table under consideration may still be applicable. Figure 3 reveals the reason. The ratio of actual to tabular volume for a tree may increase over time even if its form factor decreases, and may decrease over time even if its form factor increases.

# DISCUSSION

The results of these studies indicate that stocking levels after thinning do not have a significant effect on the stem form of upland oaks. The 12- and 15-year intervals between measurements seem sufficient to detect form changes. Form changes caused by age may mask the effect of stocking if the measurement period is much longer.

Larson (1963) points out that measurements restricted to the dominant and codominant trees may lead one to the conclusion that thinning has no effect on stem form. Other studies have reported that the failure of dominant trees to respond to thinning or release is evidently due to their strongly built, tapering stems. It can be argued, however, that the dominant and codominant trees are the trees of interest. Stem form changes in these larger trees affect volume estimates to a much greater degree than those for intermediate and suppressed trees.

There was a tendency for trees with below average form to become more "cylindrical" after thinning, and trees with above average form to "deteriorate" in form, or at least not improve as much as trees with below average form. This was the case even on the 75+ percent stocked plots. The relationship between form change and initial form should be recognized when analyzing stem form changes. Failure to do so could lead to erroneous conclusions.

We have also shown that trees that exhibit an increase in Girard Form Class may in fact show a decrease in form factor. Caution should be used when drawing conclusions about form changes when only one measure of stem form is available.

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