# CONVERSION OF SUCCESSIONALLY STABLE EVEN-AGED OAK STANDS TO AN UNEVEN-AGED STRUCTURE

**Edward F. Loewenstein and James M. Guldin**[1]

**Abstract**—Developing a silvicultural prescription to convert an even-aged or unmanaged oak stand to an uneven-aged structure depends in large part on the length of time the existing overstory will live. Four conversion prescriptions, representing three initial stand conditions, are presented. Each prescription partitions the cut of the original overstory differently in time and space depending on the interval between stand entries and the desired allocation of growing space among the newly developing age classes.

## INTRODUCTION

Oak-dominated forests of the Central and Eastern United States have generally not been regarded as suited to uneven-aged silviculture (Roach and Gingrich 1968, Sander and Clark 1971). In fact, several attempts to apply the selection method of reproduction cutting in oak-dominated stands have resulted in compositional shifts toward more shade tolerant species (Trimble 1970). Given these results, one might legitimately ask why conversion of these stands to an uneven-aged structure would be attempted, if maintenance of a dominant oak component were an objective of management.

However, empirical and experimental data suggest that under certain specific conditions, oak stands can be managed using uneven-aged methods. Many landowners are interested in managing uneven-aged stands because of the attributes that such stands provide. Among these are the maintenance of continuous forest cover in the stand, sustained yield of high-value products over time, and conditions suitable for plant and animal species that can advantageously utilize the stratified canopies and minimal harvesting impacts that are found in such stands.

In the Interior Highlands, not all stands are suitable for application of uneven-aged silviculture. Of stands that are ecologically suitable for conversion from even-aged to uneven-aged condition, efficiency of conversion depends greatly on stand condition at the beginning of the conversion process. For example, some landowners in the region, most prominently the Pioneer Forest in Salem, MO, have had great experience in creating well-structured uneven-aged upland oak stands, but these stands had their origin largely as poorly stocked cutover stands that were rehabilitated through judicious tending of residual growing stock (Loewenstein 1996, Loewenstein and others 2000). This pattern, where uneven-aged stands were created through rehabilitation of understocked conditions resulting from overcutting, has been a common theme in southern pine experience as well (Guldin and Baker 1998).

Conversely, there has been little practical or research experience in creating an uneven-aged structure from well-stocked even-aged oak stands. In this paper, a review of existing information on even-aged stand dynamics is presented from the perspective of applying that information to convert fully-stocked even-aged stands of varying ages—immature, mature, and overmature—into stands with uneven-aged structure. Emphasis is given to three elements thought to be critical to the success of such conversion—site conditions, species composition, and existing age structure. The goal of this review is to suggest working hypotheses on the patterns by which uneven-aged stands can be developed, the treatments that might be applied, and the length of time required to consider the conversion a success.

## ATTRIBUTES OF SUCCESSIONALLY STABLE EVEN-AGED OAK STANDS

Barrett (1995) broadly categorizes oak-dominated stands in the oak-hickory type as either sub-climax or successionally stable. Sub-climax stands have the highest site indices (75+ feet, base age 50 years) and are the most difficult to regenerate to oak. Succession on these sites tends toward more shade-tolerant and/or mesophytic species (Barrett 1995, Johnson 1993, Sander and Graney 1993). Successionally stable oak stands often occur on poor to medium quality sites that tend to be droughty. Few non-oaks can persist on these sites as canopy dominants (Weitzman and Trimble 1957, Roach and Gingrich 1968, Sander and Clark 1971, Barrett 1995). The selection studies that showed a compositional shift were conducted in stands that tended toward the sub-climax end of the spectrum. Conversely, single-tree selection has been shown to be a viable silvicultural alternative for maintaining an oak-dominated forest in successionally-stable stands (Loewenstein and others 1995, Loewenstein 1996, Loewenstein and others 2000).

Thus, discussion focuses on the successionally stable end of the gradient of oak-dominated stands. The methodologies presented may prove to be more or less successful (from the perspective of developing and maintaining three age classes of oak) depending on where a stand is classified along that gradient.

[1] Assistant Professor, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL; and Research Forest Ecologist and Project Leader, USDA Forest Service, Southern Research Station, Monticello, AR, respectively.

*Citation for proceedings:* Spetich, Martin A., ed. 2004. Upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS–73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 311 p.

## CONVERTING EVEN-AGED STANDS TO UNEVEN-AGED STRUCTURE

The success of conversion prescriptions depends on stand age and species composition, which determine whether the dominant overstory is capable of surviving the conversion period. Species longevity, in conjunction with stand age, gives an estimate of the time available to complete the conversion before the remaining residual overstory must be removed or until the likelihood of age-dependent mortality increases dramatically. The ability to maintain this residual overstory is not, in and of itself, integral to the conversion process; what is important is managing the growing space allocated to this age class. Widespread natural mortality of trees in the main canopy is an unpredictable event that affects both the development of trees in subordinate canopy classes and the regeneration/recruitment process. By losing control of growing space allocation, the ability to manage stand structure is compromised.

The conversion of an even-aged (single tiered canopy) stand to a multi-tiered structure (uneven-aged), and following conversion the maintenance of this structure, is accomplished by vertically partitioning growing space among age classes or cohorts. For purposes of this discussion, growing space is defined as percent stocking based on Gingrich's (1967) tree area equations and stocking chart.

Conversion prescriptions will only work if stocking of all age classes is kept closer to 58-60 percent stocking (the Gingrich 'B' line of stocking) rather than to 100 percent stocking (the Gingrich 'A' line). The 'B' line represents the low end of full stocking in a stand, assuming a uniform distribution of trees across the site; each tree is at maximum crown spread and there are no gaps between adjacent crowns. A stand at 'B' level stocking is allocating growth to significantly fewer trees than is a stand approaching 100 percent stocking, and this will be important during the conversion process.

Three conversion prescriptions will be discussed, based on stand age—conversion of immature stands, mature stands, and overmature stands. Within the mature stand condition, two patterns of conversion—uniform conversion and patch conversion—will also be discussed.

### Immature Stands

In this prescription, a fully stocked young stand must be heavily cut during the initial entry; as a result, residual stocking levels will be quite low in the early years of the conversion (table 1a). This heavy cut is needed because young stands grow rapidly, and will quickly reoccupy the available growing space. Stands subject to this prescription must be followed closely lest stocking accrue to the point where the Gingrich 'B' line is approached.

The prescription applies to stands that are immature and fully stocked. It can also be used in situations where the landowner wishes to develop an uneven-aged state, but the existing stand does not lend itself to conversion. In such a situation, the stand is regenerated, and the succeeding even-aged stand is allowed to develop for approximately 30 years before the conversion is attempted.

**Table 1—Levels of stocking by cohort and year used to implement three prescriptions to convert successionally stable even-aged oak stands to uneven-aged structure**

| | Cohort | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | *- - - - - - - - - - - percent stocking - - - - - - - - - - -* | | | | | | |
| | **a. Immature stands** | | | | | | |
| C-30 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| C-15 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| C | 30 | 30 | 0 | 0 | 0 | 0 | 0 |
| C+15 | 30 | 30 | 0 | 0 | 0 | 0 | 0 |
| C+30 | 30 | 20 | 10 | 0 | 0 | 0 | 0 |
| C+45 | 30 | 20 | 10 | 0 | 0 | 0 | 0 |
| C+60 | 0 | 30 | 20 | 10 | 0 | 0 | 0 |
| C+75 | 0 | 30 | 20 | 10 | 0 | 0 | 0 |
| C+90 | 0 | 0 | 30 | 20 | 10 | 0 | 0 |
| C+105 | 0 | 0 | 30 | 20 | 10 | 0 | 0 |
| C+120 | 0 | 0 | 0 | 30 | 20 | 10 | 0 |
| C+135 | 0 | 0 | 0 | 30 | 20 | 10 | 0 |
| C+150 | 0 | 0 | 0 | 0 | 30 | 20 | 10 |
| | **b. Mature stands** | | | | | | |
| C-30 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| C-15 | 66 | 0 | 0 | 0 | 0 | 0 | 0 |
| C | 50 | 10 | 0 | 0 | 0 | 0 | 0 |
| C+15 | 40 | 20 | 0 | 0 | 0 | 0 | 0 |
| C+30 | 30 | 20 | 10 | 0 | 0 | 0 | 0 |
| C+45 | 30 | 20 | 10 | 0 | 0 | 0 | 0 |
| C+60 | 0 | 30 | 20 | 10 | 0 | 0 | 0 |
| C+75 | 0 | 30 | 20 | 10 | 0 | 0 | 0 |
| C+90 | 0 | 0 | 30 | 20 | 10 | 0 | 0 |
| C+105 | 0 | 0 | 30 | 20 | 10 | 0 | 0 |
| C+120 | 0 | 0 | 0 | 30 | 20 | 10 | 0 |
| C+135 | 0 | 0 | 0 | 30 | 20 | 10 | 0 |
| C+150 | 0 | 0 | 0 | 0 | 30 | 20 | 10 |
| | **c. Overmature stands** | | | | | | |
| C-30 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| C-15 | 66 | 0 | 0 | 0 | 0 | 0 | 0 |
| C | 40 | 20 | 0 | 0 | 0 | 0 | 0 |
| C+15 | 30 | 30 | 0 | 0 | 0 | 0 | 0 |
| C+30 | 0 | 40 | 20 | 0 | 0 | 0 | 0 |
| C+45 | 0 | 40 | 20 | 0 | 0 | 0 | 0 |
| C+60 | 0 | 30 | 20 | 10 | 0 | 0 | 0 |
| C+75 | 0 | 30 | 20 | 10 | 0 | 0 | 0 |
| C+90 | 0 | 0 | 30 | 20 | 10 | 0 | 0 |
| C+105 | 0 | 0 | 30 | 20 | 10 | 0 | 0 |
| C+120 | 0 | 0 | 0 | 30 | 20 | 10 | 0 |
| C+135 | 0 | 0 | 0 | 30 | 20 | 10 | 0 |
| C+150 | 0 | 0 | 0 | 0 | 30 | 20 | 10 |

However, even if the prescription is properly implemented, the methodology is highly inefficient in that it requires investments that are not immediately recovered. Depending on the size of the dominant overstory and local markets for small diameter stems, there may be little income generated from the stand during the conversion process. Each entry may amount to a pre-commercial thinning. Thus, this prescription should be implemented only with the understanding that the desire for an uneven-aged stand outweighs the costs of conversion.

Regeneration in this prescription is obtained almost exclusively from stump sprouting during the first cutting cycle entries. By age 30, most oak stands are not yet producing large quantities of acorns and the stand is sufficiently dense that accumulation of advance reproduction has not begun. By thinning the stand to approximately 30 percent stocking, only the largest, most vigorous trees with the best form are retained. In particular, one would select against trees that show a propensity for epicormic branching because these residual trees will be open grown, similar to the leave trees in an irregular shelterwood (see Miller 1996). The second age class is recruited from stump sprouts and the stand is allowed to develop for another 30 years at which time the dominant canopy tier has grown to approximately 55-58 percent (approaching ‘B’ line) stocking.

A cutting cycle of thirty years is possible only because the residual stocking was reduced to 30 percent. If stocking had not been reduced so dramatically, or if growth rates were such that the dominant canopy class were to reach full stocking (B-line) before 30 years had passed, then the stand would have to be reentered in order to keep the subordinate age class alive. It is important to note that the point a stand must be reentered is before the dominant canopy reaches 58-60 percent stocking (the B-line), not at 100 percent stocking (A-line). As the dominant canopy layer approaches B level stocking, it is fully occupying the available growing space in the stand. This leaves all subordinate canopy layers with no free growing space. In reality, this point is reached somewhere above the B-line because the distribution of trees in a stand is not perfectly uniform; however, the concept still applies.

Following the first cutting cycle, overstory stocking is again reduced to approximately 30 percent stocking and the midstory is thinned to 20 percent stocking. The third age class is recruited primarily from stump sprouts, supplemented by advance reproduction. This second entry completes the conversion. Three age classes have been established and future stand entries are directed toward the maintenance of the existing stand structure (see Larsen and others 1999). The conversion is accomplished in thirty years, sixty if it were initiated by an even-aged regeneration of the stand (table 1).

### Mature Stand, Uniform Reduction

In this second prescription, one is dealing with a fully stocked stand of mature trees, a portion of which must be capable of surviving an additional 60 to 70 years. This conversion prescription calls for a uniform treatment across the stand and because of this, the product yield during the conversion process may fluctuate greatly across cutting cycles. However, because the trees being managed are of larger size, each entry should produce commercial harvests of timber and should generate income for the landowner.

For the initial entry, stand stocking should be reduced by no more than one-third (to not less than 60 percent stocking) in an operation similar to the preparatory cut of a shelterwood (table 1b). This harvest is designed to increase the vigor of the residual overstory trees so they are less likely to degrade when the stand is opened further; an ancillary outcome is to develop the advance reproduction in the understory that will become the second age class. The amount of time between this harvest and the second is not critical because its primary goal was not to establish a new cohort. The second entry is made when the residual trees have increased crown spread and some advance reproduction has developed (approximately 5–15 years). However, if significant crown dieback occurs, possible in the shorter-lived or less vigorous residuals, then the timing of the second entry should be moved up to salvage the potential loss.

The second cutting-cycle harvest reduces overstory stocking to approximately 50 percent and is designed to recruit the first new age class of the conversion process. Any tree deemed likely to die or significantly degrade prior to the next harvest entry is removed. Beyond that, the best trees are left as uniformly as possible across the stand to meet the desired stocking level. Note that only 10 percent of available growing space is allocated to the new age class; 50 percent stocking is retained in the overstory, which leaves only 10 percent available for establishment of the new cohort. By retaining much of the growing space in the dominant canopy tier, the density of the newly established cohort is kept fairly low. This later reduces the amount of precommercial thinning needed when the next cohort is recruited at the subsequent cutting cycle harvest. However, the stocking of the dominant canopy tier(s) must be kept sufficiently low to maintain the vigor of the most subordinate age class throughout the cutting cycle. Thus, residual stocking levels and growth rates determine the length of the cutting cycle.

The vigor of the most subordinate age class is a function of the relative density of all superior age classes. When the dominant canopy tiers reach full stocking, density dependent mortality of the understory begins. The level of residual stocking can be modified in the event that a shorter or longer cutting cycle is desired; in this case, a 15-year cutting cycle is initially suggested.

At the end of the first cutting cycle, the dominant canopy tier is reduced to 40 percent stocking leaving approximately 20 percent free growing space for the developing understory layer. During this entry, the objective is not to develop a third age class. One only seeks to ensure that the second age class maintains sufficient growing space for continued development. Thus, even if the second age class occupies more than 20 percent stocking (growing space), it is left untreated. Following the second cutting cycle, the overstory is reduced in stocking to 30 percent, and the midstory to 20 percent, leaving approximately 10 percent free growing space for the establishment of a third age class. Following conversion, as canopy tiers become less distinct, the distribution of stocking between age classes is most easily allocated among size classes: sawtimber (overstory), poles (midstory), and seedlings/saplings (reproduction/understory).

There is no need to establish a new cohort with each entry. For an uneven-aged stand, only three age classes are required. Therefore, it is possible to regenerate a new cohort every second, third, or fourth entry into the stand depending on the age of the oldest cohort and the length of the cutting cycle. If such is the case, total stand stocking should not be reduced to 50 percent until a regeneration event is desired. Reduce stocking in the two superior canopy tiers enough to ensure the most subordinate canopy class remains vigorous [e.g., thin all trees >5 inches in diameter at breast height ((d.b.h.)] to 50 percent stocking, thus leaving 10 percent growing space for the most subordinate class).

The suggested ratio of stocking among size/age classes (30:20:10) approximates a *q*-value of 1.3 (for 2-inch diameter classes). It maintains 70 percent of the stand basal area in the sawtimber size classes and ensures sufficient numbers of trees in the smaller size classes to sustain ingrowth while allowing for natural mortality, crop tree selection, and timber harvest. This stand structure has been found sustainable in the Ozark Highlands of Missouri (Loewenstein 1996, Larsen and others 1999, Loewenstein and others 2000). Using this ratio of growing space among age classes during stand conversion facilitates structural maintenance thereafter.

### Mature Stand, Patch Reduction

In this third prescription for conversion, one is also dealing with a mature stand of trees, and one uses the same stocking levels as outlined for the uniform conversion (table 1b). However, the pattern of implementation is different.

Under this methodology, new cohorts are developed with each entry, but not across the entire stand. Unlike the uniform conversion prescription, the start of the conversion is staggered in patches across the stand. The initial reduction in stand stocking is the same between the two methods, a uniform reduction across the entire stand of one-third to not less than 60 percent stocking. Following the first entry, patches within the stand (for illustration, say 20 percent of stand area in patches of different size and pattern) are reduced in stocking to 50 percent to establish the second age class. Throughout the matrix of the stand between the patches, trees that are unlikely to survive the cutting cycle are marked for removal, otherwise stocking is maintained between 60 and 75 percent. After one cutting cycle, another 20 percent of patch area across the stand is reduced to 50 percent stocking; the section initially treated is reduced to 40 percent stocking, and the remaining 60 percent of the stand is examined for potential mortality and thinned to retain vigor. The cycle is continued until the entire stand has received the full series of conversion entries described in the uniform method, at which time the dominant overstory of the last portion of the stand is 175 years old (assuming the series was initiated in a 60-year-old stand). Each 20 percent portion of the stand may be treated as a contiguous block, or may be treated as several smaller patches that together equal 20 percent.

This patch approach to conversion results in a more even flow of timber throughout the conversion process and has the potential to ensure a regular income and a merchantable harvest with each entry. However, the ability to use this approach is dependent on the size of the ownership and local market conditions, which determine whether harvests of a given volume are operable. Mature patch conversion is also constrained by the age and species composition of the stand. Under this scenario, the length of time required to complete the conversion may extend from 30 to 60 years beyond that of the uniform reduction strategy.

### Overmature Stands or Short-Lived Species

Finally, one should consider those situations where the existing dominant canopy will not survive the conversion period. The immature method is applicable when the overstory trees in a stand either should not be retained or where they will only survive the establishment of a single new age class. The two mature stand methods assume that the overstory is capable of surviving the entire conversion process (three new age classes). If, however, the dominant overstory is expected to die after the establishment of the second age class, one should modify the allocation of growing space during initial stand entries so that control of density in the most subordinate age class becomes paramount. These stands need to be regenerated as soon as possible, and this prescription ensures that outcome (table 1c).

Wherever possible, the dominant overstory should be retained for as long as it can be maintained in a vigorous condition. However, in the case of an overmature stand, a substantially greater portion of the growing space must be allocated to the first cohort established during the conversion process because it will be used to constrain density in succeeding cohorts.

The preparatory thinning is similar to the uniform methods. Stocking is reduced uniformly by no more than one third to not less than 60 percent stocking. The first cutting cycle reduces overstory stocking to 40 percent, allocating 20 percent to the first new cohort. The second cutting cycle reduces overstory density to 30 percent stocking, leaving 30 percent for the subordinate age class. The third cutting cycle removes the original overstory rather than allowing it to die piecemeal over time. The first cohort is thinned to 40 percent stocking, allocating 20 percent to the second cohort. The first cohort is cut back to 40 percent during the fourth cutting cycle; no treatment is required in the subordinate cohort. Conversion is completed with the fifth cutting cycle; the first cohort is thinned to 30 percent stocking and the second cohort to 20 percent, leaving 10 percent stocking available for the establishment of a third.

### Stand Structure—Is *q* Relevant During Conversion?

All of these prescriptions have one attribute in common—aggressive efforts to develop new age classes when called to do so. Eventually, a more formalized uneven-aged regulation method will be implemented to supplement and guide the retention of given levels of stocking in the different age classes. Thus, structural control will become essential for creating and maintaining an uneven-aged stand. During conversion, growing space has been allocated based solely on canopy position. Yet, it was never suggested that during the conversion period the stand should be marked to a guiding curve. Although a *q* based (or similar) approach is essential for maintaining an uneven-aged structure in an oak-dominated system (Larsen and others 1999), *q* has no place in stand conversion!

Conversion of a stand to an uneven-aged structure cannot be accomplished in the same manner as the maintenance of stand structure in an existing uneven-aged stand. During the conversion process, one should be treating each age class independently, thinning each from below—in effect, cut the worst and leave the best (Baker and others 1996) within an age class. Unfortunately, following conversion when one has three age-classes intermingled intimately on the same area, canopy tiers become less distinct; thus, it becomes more difficult to thin each cohort from below. It becomes increasingly difficult to recognize the difference between age classes (trees from all three age classes may be found in the same diameter class). The guiding curve is simply a methodology for ensuring the maintenance of a sustainable stand structure. It differs from the conversion prescriptions in that one would cut the worst from each size class (rather than age class) and growing space is allocated by diameter class (rather than by age class).

## SUMMARY

The choice of a conversion strategy is most dependent on the expected longevity of the dominant overstory. If it will survive the establishment of one new age class, or if it is an immature stand, use the immature method. If it will survive the establishment of two new age classes, use the overmature method. If a substantial portion of the original overstory will survive the establishment of three new age classes, then either of the two mature stand methods is appropriate.

The goal at the end of conversion is to have partitioned growing space (stocking) among age classes/canopy tiers in a ratio of 30:20:10. This stand structure maintains a large proportion of the growing space in sawtimber and controls the density of small diameter trees (reducing the need for pre-commercial thinning). Even so, it allocates sufficient growing space to the most subordinate age class ensuring sustainable recruitment into the overstory.

The length of the cutting cycle is affected by residual stand density and growth rates. If a longer cutting cycle is desired, residual stand density must be reduced. Otherwise, one increases the risk of losing the youngest age class in the stand. Density dependent mortality begins in the most subordinate age class when the stocking level of all trees in a superior crown position reach full stocking.

There is no need to recruit a new cohort of trees into the stand with each cutting cycle. To recruit a new cohort, total stand stocking must be reduced to approximately 50 percent; this should be done only when needed to maintain three age classes in the stand. Alternatively, stocking of the midstory and overstory should be reduced to 50 percent, leaving 10 percent stocking available for the existing understory, thus maintaining a fully stocked stand.

## ACKNOWLEDGMENTS

The authors would like to gratefully acknowledge the USDA Forest Service, North Central Research Station, for their support of the research leading to the development of this paper.

## LITERATURE CITED

Baker, J.B.; Cain, M.D.; Guldin, J.M. [and others]. 1996. Uneven-aged silviculture for the loblolly and shortleaf pine forest cover types. Gen. Tech. Rep. SO-118. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC. 65 p.

Barrett, J.W., ed. 1995. Regional silviculture of the United States. 3rd edition, John Wiley and Sons, New York. 551 p.

Gin[g]rich, S.F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the Central States. Forest Science 13: 38-53.

Guldin, James M.; Baker, James B. 1998. Uneven-aged silviculture, southern style. Journal of Forestry 96(7): 22-26.

Johnson, P.S. 1993. Perspectives on the ecology and silviculture of oak-dominated forests in the Central and Eastern States. Gen. Tech. Rep. NC-153. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, St. Paul, MN. 28 p.

Larsen, D.R.; Loewenstein, E.F.; Johnson, P.S. 1999. Sustaining recruitment of oak reproduction in uneven-aged stands in the Ozark Highlands. Gen. Tech. Rep. NC-203. U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN. 11 p.

Loewenstein, E.F. 1996. An analysis of the size- and age-structure of an uneven-aged oak forest. Columbia, MO: University of Missouri. 167 p. Ph.D. dissertation.

Loewenstein, E.F.; Garrett, H.E.; Johnson, P.S.; Dwyer, J.P. 1995. Changes in a Missouri Ozark oak-hickory forest during 40 years of uneven-aged management. p 159-64. In: Proceedings, 10th Central Hardwood Forest Conference. Gottschalk, K.W.; Fosbroke, S.L.C. (eds.). Gen. Tech. Rep. NE-197. U.S. Department of Agriculture, Forest Service Northeastern Forest Experiment Station, Radnor, PA. 577 p.

Loewenstein, E.F.; Johnson, P.S.; Garrett, H.E. 2000. Age and diameter structure of a managed uneven-aged oak forest. Canadian Journal of Forest Research 30(7): 1060-70.

Miller, G.W. 1996. Epicormic branching on central Appalachian hardwoods 10 years after deferment cutting. Res. Pap. NE-702. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Radnor, PA. 9 p.

Roach, B.A.; Gingrich, S.F. 1968. Even-aged silviculture for upland central hardwoods. Ag. Hdbk. 355. U.S. Department of Agriculture, Forest Service, Washington D.C. 39 p.

Sander, I.L.; Clark, F.B. 1971. Reproduction of upland hardwood forests in the Central States. Agriculture Handbook 405. U.S. Department of Agriculture, Forest Service, Washington, D.C. 25 p.

Sander, I.L.; Graney, D.L. 1993. Regenerating oaks in the Central States. p 174-83. In: Oak Regeneration: Serious Problems, Practical Recommendations. Loftis, D.L.; McGee, C.E. (eds.). Gen. Tech. Rep. SE-84. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Asheville, NC. 319 p.

Trimble, G.R., Jr. 1970. Twenty years of intensive uneven-aged management: effect on growth, yield, and species composition in two hardwood stands in West Virginia. Res. Pap. NE-154. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA. 12 p.

Weitzman, S.; Trimble, G.R., Jr. 1957. Some natural factors that govern the management of oaks. Stn. Pap. No. 88. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA. 40 p.