SPECIES COMPOSITION, DIAMETER DISTRIBUTION, AND CROWN CLASS AT INITIATION OF A THINNING STUDY OF POLE-SIZE HARDWOOD STANDS IN THE HOOSIER NATIONAL FOREST

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Abstract.—During the spring of 2007, a low thinning was implemented in stands on the Hoosier National Forest that had been clearcut harvested between 1975 and 1979; treatments consisted of 60- and 75-percent residual stocking, as well as control plots with no thinning. The 60-percent treatment increased the relative oak density per acre in all stands with the exception of one stand that contained no oak component prior to thinning. The 75-percent stocking treatment resulted in only marginal increases in relative oak density. Relative density increases for yellow-poplar and black cherry were greater in 60-percent treatment plots than in 75. Conversely, 75-percent treatment plots had nearly twice the relative density of other hardwoods compared to that of the 60-percent plots. Mean diameter distribution in the 60-percent plots showed a more pronounced increase in diameter than that of the 75-percent plots. These preliminary differences resulted from a greater stocking removal of stems in the lower crown and diameter classes in the 60-percent treatment plots.

INTRODUCTION

Mid- to late-successional, shade intolerant species such as oaks (*Quercus* spp.) are an integral component to the ecology and economy in many areas of the Central Hardwood Forest Region. They have proven difficult to regenerate and maintain without proper silvicultural management. It has been well documented that even-aged management is the preferred and most successful method of regenerating intolerant species (Johnson and others 2002). However, these methods often fail to achieve adequate oak regeneration without additional intermediate treatments (Abrams and Nowacki 1992, Jenkins and Parker 1998, Johnson and others 2002).

The success of even-aged silvicultural methods in regenerating oaks is frequently limited to the stem initiation stage. During the stem exclusion phase, however, oaks are relatively low in number compared to early successional species, such as yellow-poplar (*Liriodendro tulipifera* L.) (Fischer 1987, Brashears and others 2004) and black cherry (*Prunus serotina* Ehrh.) (Schuler 2006). Even-aged regeneration methods produce a high number of stems per unit area, which results in increased competition among stems, slower growth rates, suppressed stems, and eventually mortality (Oliver and Larson 1996). Species such as yellow-poplar and black cherry are especially problematic because of their ability to exploit available growing space through rapid growth and subsequently suppress slower-growing species like oaks (Schuler 2006). This process can delay economic maturity, as well as be ecologically detrimental to a stand as undesirable species are established. A common silvicultural prescription to mitigate these effects is thinning.

Thinning regimes may help to increase stand productivity and value, attain desirable species composition, and select future crop trees. Thinning serves to allocate a greater amount of growing space to fewer stems through the removal of others (Johnson and others 2002). The reduction in competition produces favorable growing conditions for residual trees by increasing available sunlight (Hale 2001), soil moisture

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(Concilio and others 2005, McCarthy and Brown 2006), and nutrients (Thibodeau and others 2000). Studies have shown thinning can increase diameter growth of residual trees at various stages of stand development. For example, Lamson and Smith (1978) reported diameter increases in stands 9 years of age and Nowak and Marquis (1997) found increased diameter growth in mature stands 70 years of age as a result of thinning. Additionally, Gingrich (1970) showed that board-foot volume yield in upland central hardwood stands could be doubled by thinning stands early and frequently throughout their development compared to unthinned stands. Thinning also provides an opportunity to improve stand structure in terms of species composition and diameter distribution. Harvesting undesirable species and stems with poor vigor or form can increase the proportion of desirable species and crop trees.

Although stand productivity may increase as a result of allocating additional growing space to fewer trees, there are several potential risks. Excessive thinning could jeopardize wood quality (Dale and Sonderman 1984), increase the chance of windthrow, or promote vigorous growth of understory vegetation, thereby inadvertently increasing competition for site resources (Smith and others 1997). Conversely, removing too few stems may result in lost opportunity to improve growth rates, shorter period for re-entry, longer return of invested capital, and incomplete utilization of growing space (Daniel and others 1979, Johnson and others 2002).

Deciding upon the appropriate level of thinning is vital to achieving maximum board-foot volume yield. The challenge in determining the appropriate stand density is to provide an abundant amount of growing space without reducing total stand productivity or quality. Gingrich (1967) conducted an intensive study in predominately upland oak-hickory stands to develop a well defined range of stand densities that would maximize stand growth. Gingrich's stocking guide is based on the theory that growing space utilized by an individual tree is dependent on the size of the tree and its associated diameter and is intended to assist forest managers in determining appropriate silvicultural prescriptions given the current density of a stand. Gingrich (1967) identified A (overstocked), B (fully stocked), and C (understocked) levels of stocking; stands that have stocking below the C level are typically not deemed worth managing (Parker and Merritt 1995). Roach and Gingrich (1968) found that in stands with high initial stocking, such as clearcuts, reductions of stocking should be gradual in order to help ensure there is not a surplus of growing space and to reduce the likelihood of poor stem quality from epicormic branching.

OBJECTIVES

This paper reports baseline changes in species composition, diameter distribution, and crown class after thinning treatments were implemented to characterize the effects of density reductions. Hilt and Dale (1987) found that oak, yellow-poplar, and other hardwoods species comprised 10, 5, and 85 percent respectively of the 40 largest trees per acre in a 21-year-old even-aged central hardwood stand after implementing a free thinning to 50-percent residual stocking. They also found that oak, yellow-poplar, and other hardwood species comprised 17, 17, and 64 percent, respectively, of the 40 largest trees in a 21-year-old stand after thinning to 70 percent stocking. Both stocking levels showed an increase in the oak component compared to the control, which contained 6, 13, and 81 percent of oak, yellow-poplar, and other hardwood species, respectively. Dale and Sonderman (1984) conducted a free thinning in a 33-year-old predominantly white oak stand in Kentucky and found the relative density of dominant and codominant stems in stands with 60 and 45 square feet per acre of residual basal area to be 271 and 214 stems per acre, respectively, compared to 279 stems per acre in the control plots. Dale and Sonderman (1984) also observed an increase in quadratic mean diameter in each crown class as residual stocking decreased. These studies are examples of how thinning can directly improve stand structure and composition through initial changes in species composition and diameter distribution. However, they do not take into account the crown position of individual species (i.e., oaks, yellow-poplar, and black cherry), which has been shown to be critical to maintaining those species in the stand (Fischer 1987, Brashears and others 2004, Schuler 2006). Therefore, to better understand the effects of density reduction on short-term stand dynamics, the objective of this study is to characterize changes in stand structure, in particular reference to oaks, resulting from different levels of density reduction from low thinning.

STUDY AREA

This study was conducted in the Hoosier National Forest (HNF). The HNF is composed of upland hardwoods and is located in the unglaciated central portion of southern Indiana. The experimental sites of this study are located within the Tell City Management Unit; the area lies within the Crawford Upland subsection of the Shawnee Hills section of the Interior Low Plateau as defined by Homoya and others (1985). The topography of this region consists of numerous hills composed of acid silt loams of the Wellston-Zanesville-Berks association that were formed from sandstone-loess and marked by sandstone outcrops and rock shelters (Homoya and others 1985).

This study monitored five stands that were clearcut harvested between 1975 and 1979. Each stand was evaluated in the spring of 2006 and selected based on the criteria that they were a minimum of 20 acres in size, naturally regenerated following clearcut harvesting, free from large blowdown, insect or disease events, and had only infrequent occurrence of grapevines (*Vitis* spp. L.) in the regenerating stands. Stand density for these five stands ranged from approximately 725 stems per acre to 1,500 stems per acre and all stands were found to be at approximately 100-percent stocking. Species composition varied greatly, with the most common species being white oak (*Quercus alba* L.), yellow-poplar (*Liriodendro tulipifera* L.), black cherry (*Prunus serotina* Ehrh.), scarlet oak (*Quercus coccinea* Muenchh), and sugar maple (*Acer saccharum* Marsh.).

METHODS

In the fall of 2006, three relatively homogenous 1-acre treatment plots were located within each of the five stands with a 70-foot treatment buffer surrounding each treatment plot. Four permanent 0.1-acre subplots were installed within each of the 1-acre treatment plots. All stems 1 inch and greater in diameter at breast height (d.b.h.) were inventoried in each of the subplots prior to thinning; species, d.b.h., and crown class were recorded for each stem. Treatments were randomly assigned to plots at three levels of residual stocking, based on Gingrich's (1967) stocking guide for upland central hardwoods. Gingrich (1967) found that stands did not fully utilize the available growing space below the B level or below 57-percent stocking; therefore, it is not recommended to reduce stocking more than 40 percent in a stand that is near 100-percent stocking. The suggested minimum residual stocking level of 60 percent and moderate level of 75 percent were therefore the chosen treatments in this study.

Thinning from below, often referred to as low thinning, was used to achieve the desired stocking levels. This method has been shown to decrease the relative proportion of undesirable species or low quality stems, as well as to increase average tree size (Meadow 1993). The removal of the lower-class trees simulates an increased rate of natural mortality from self-thinning during the stem exclusion stage (Smith and others 1997) and results in allocating more growing space to larger-diameter trees. This method is preferred because it can be implemented with very little risk of reducing gross stand production (Smith and others 1997). Stems in the lower crown class are not preferred for release as they often do not recover from being

Table 1.—Number of stems per acre (n) and change in relative density (RD) per acre for dominant and codominant stems of four species groups in each treatment after thinning

Species group	Stocking	Stand 1 n	Stand 1 Change	Stand 2 n	Stand 2 Change	Stand 3 n	Stand 3 Change	Stand 4 n	Stand 4 Change	Stand 5 n	Stand 5 Change
Oak	100%	87	0%	68	0%	248	0%	10	0%	180	0%
	75%	115	7%	40	0%	198	4%	20	4%	173	0%
	60%	33	5%	95	11%	270	20%	0	0%	165	17%
Yellow-poplar	100%	33	0%	68	0%	0	0%	45	0%	18	0%
	75%	13	0%	3	-1%	0	0%	80	-3%	0	0%
	60%	35	3%	3	-1%	0	0%	30	8%	0	0%
Black cherry	100%	50	0%	90	0%	5	0%	133	0%	35	0%
	75%	23	-3%	70	-2%	18	-4%	15	1%	35	-2%
	60%	53	1%	38	4%	50	9%	18	5%	38	3%
Other hardwoods	100%	95	0%	328	0%	115	0%	78	0%	180	0%
	75%	100	-7%	200	-4%	43	0%	48	3%	223	0%
	60%	115	-8%	125	-15%	23	-29%	60	-14%	75	-20%

suppressed over long periods of high competition. However, stems in the upper canopy are likely more vigorous, of higher quality, and better suited for the site (Gingrich 1971).

The hierarchy for species favored as leave trees was based on the species' ecological and economic importance and the probability that it would be a component of the stand at the end of rotation. Dominant and codominant oaks were favored over dominant and codominant black cherry and yellow-poplar due to oaks' inability to successfully compete with the faster-growing species, such as black cherry and yellow-poplar, during the stem exclusion phase. One-acre treatment plots and associated buffers were thinned to designated stocking levels in spring, 2007. Each subplot was re-inventoried after thinning was completed. Changes in species composition, d.b.h, and crown class were evaluated by direct comparison of pre- and post-thinned subplots within each treatment, as well as between treatments.

RESULTS

The 60-percent residual stocked plots in four out of five stands showed an increase in the relative density (RD) per acre of oak stems in the dominant and codominant crown class (Table 1); the only stand that did not show an increase in oak was that which had no oak component prior to thinning. This increase in RD resulted in an increase of 54, 28, 10, 2, and 0 oak stems per acre in the main canopy. Sixty-percent residual stocked plots showed marginal changes in the RD of yellow-poplar. Only one stand showed a minor decrease in the RD of yellow-poplar, whereas stand four showed an eight percent increase. Unlike yellow-poplar, the RD of dominant and codominant black cherry increased in all five stands (1, 4, 9, 5, and 3 percent), the greatest increase (9 percent) was equivalent to only five more stems per acre in the main canopy. Dominant and codominant stems in the other hardwoods group showed a consistent and rather large decrease in RD compared to the other three groups.

In contrast to the 60-percent stocking treatment, there was little change in the RD of oak in the 75-percent stocked plots. Three of the five stands showed little increase in relative oak density and two showed no change at all (Table 1). Similarly, the RD of yellow-poplar decreased slightly in two stands and remained

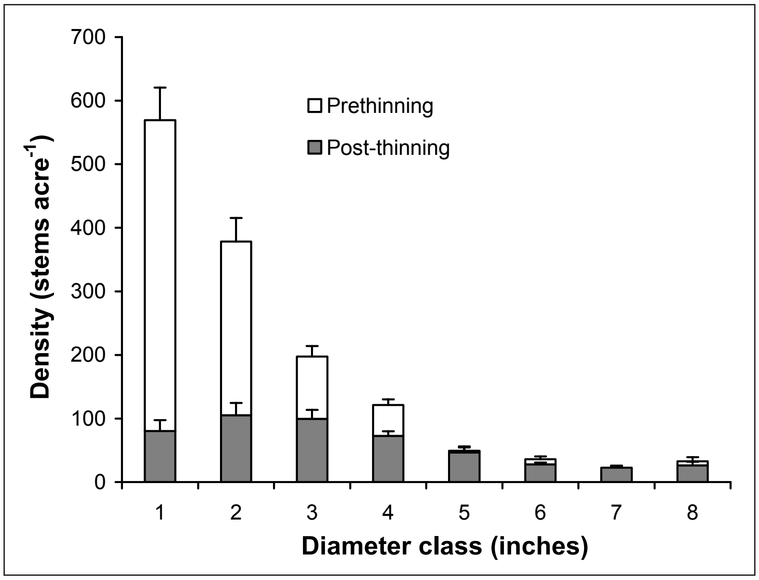

Figure 1.—Mean per acre diameter distribution of five stands for 60-percent stocked plots prethinning and post-thinning.

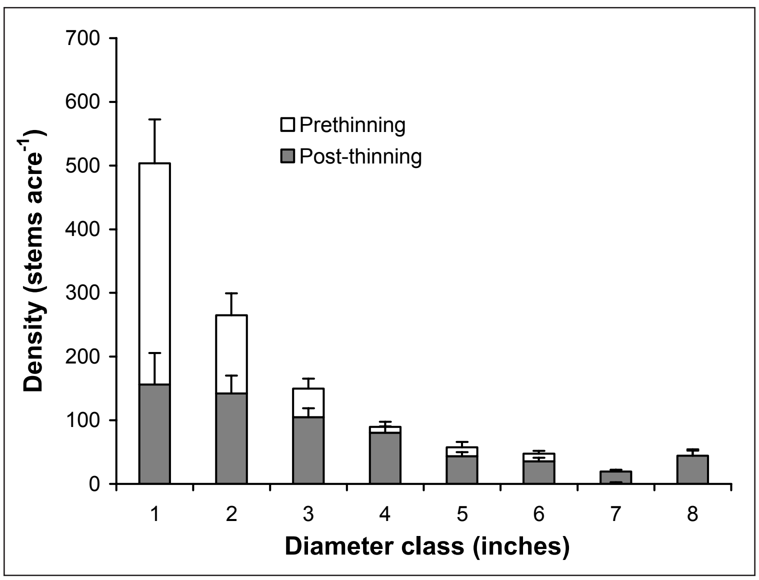

Figure 2.—Mean per acre diameter distribution of five stands for 75-percent stocked plots prethinning and post-thinning.

the same in another. Unlike the 60-percent stocking treatment, black cherry decreased in all but one stand, in which it increased by 1 percent. The large decrease in the other hardwoods group was not observed in the 75-percent stocking treatment as it was in the 60 percent.

The effect of thinning from below to obtain the desired stocking levels is apparent in the diameter distributions in Figures 1 and 2. An average of 912 stems per acre were removed from the 60-percent treatment plots; 96 percent of these stems were in the 1-, 2- , and 3-inch diameter classes (54, 31, and 11 percent, respectively). An average of 610 stems per acre were removed to achieve 75-percent stocking; the 1-, 2-, and 3-inch diameter classes comprised 90 percent of the removal; 60, 22, and 8 percent, respectively. The mean diameter distribution for 60-percent stocked plots (Fig. 1) showed a predominant shift from the typical reversed J-shaped curve to a more even distribution among diameter classes. The mean diameter distribution for the 75-percent stocked plots (Fig. 2), however, showed subtle changes and still resembles a reverse J-shaped curve.

DISCUSSION

Although the first thinning of a previously unthinned stand may produce the greatest intermediate yield (Gingrich 1971), it should be noted that these treatments were merely the beginning of a thinning schedule and that these stands should undergo subsequent thinning to further improve stand productivity and structure. Changes in species composition and diameter distribution from this initial thinning will influence the dynamics of these stands over the next 10 years as well as the subsequent thinning prescription.

The greatest impact on stand growth and structure through thinning can be made during the stem exclusion phase (Shifley 2004). Thinnings provide an opportunity to improve stand quality by changing species composition, improving tree spacing, and promoting the vigor of residual trees (Sonderman 1984, Gingrich 1970). A greater proportion of oaks in the upper canopy positions is especially important in maintaining the oak component in stands with highly competitive species like yellow-poplar and black cherry (Brashears and others 2004). This study demonstrates that the RD of dominant and codominant oaks can be maintained and even increased, by thinning from below (Table 1). Similar results were found by Hilt and Dale (1987), in which percentage of oaks in the largest 40 trees per acre increased as stocking decreased. The 75-percent stocked plots of stands two and five did not show an increase in the RD of oak as did the other three stands, and only marginal decreases of black cherry and other hardwoods were observed. Both the 60- and 75-percent treatments did not produce a large decrease in the highly competitive yellow-poplar and black cherry groups. This outcome indicates that residual stocking below 60 percent or an alternative thinning method may be needed to decrease those species' densities relative to oak. The more intense thinning could show reductions in yellow-poplar and black cherry similar to those observed in the hardwoods group between 75 and 60 percent stocking; the additional 15-percent stocking reduction resulted in large and consistent decreases in the hardwoods group. Shifley (2004) suggested that maintaining trees in the dominant and codominant canopy position is vital to increasing individual tree growth and stand productivity. Though the two treatments were able to at least sustain the RD of dominant and codominant oaks, it is unknown if these stems will be able to maintain their position. Schuler (2006) found that in 23-year-old stands of black cherry and northern red oak, a crown-touching release reduced the height growth of treated black cherry, while northern red oak was not affected. The crown-touching release allowed the northern red oak to gain a competitive advantage in height growth. The 60- and 75-percent stocking levels in this study may provide enough growing space to cause faster-growing species to allocate photosynthate for increased diameter growth and thus, reduce growth in height. This process could allow the slower-growing oaks an opportunity to increase their height and maintain or improve their canopy position.

As expected, thinning from below increased average stem diameter in both treatments (Figs. 1 and 2). The shift toward a larger diameter distribution was more pronounced in the 60 percent stocking treatments. While on average, a greater percentage of 1-inch diameter stems were removed from the 75-percent plots, the mean diameter distribution for 75-percent plots maintained the reverse J-shaped curve. As a result more growing space was allocated to larger-diameter trees in the 60-percent plots compared to that of the 75 percent. Dale and Sonderman (1984) found similar results as quadratic mean stem diameter increased for each crown class as residual stocking decreased. The additional 1- and 2-inch diameter stems in the 75-percent treatments suggest that the lighter thinning did not fully simulate the stem exclusion phase of stand development. However, Dale (1968) found that net basal area growth reached a maximum between 40 and 60 percent stocking in 25- to 35-year-old white oak stands in Kentucky and Iowa. He also concluded that net growth decreased at stocking above 60 percent due to natural mortality. Hilt (1979) observed little differences in periodic annual d.b.h. growth between medium (46-65 percent) and high stocking (66-80) levels in 23- to 34-year-old mixed oak stands. Conversely, Roach and Gingrich (1968) contend that with proper spacing, each tree has an adequate amount of growing space at the B stocking level (approximately 60 percent).

Dale (1968) reported that the majority of the growth response in 50-percent stocked plots of a 25-year-old Iowa stand and a 35-year-old Kentucky stand occurred by the second year after thinning and that growth was maintained through the third and fourth year. Dale (1968) also concluded that mean annual diameter growth of the largest white oak stems at 50 percent stocking showed 70- and 35-percent increase in the Iowa and Kentucky stands, respectively, compared to the largest white oaks in fully stocked stands over a 4-year period. Sonderman (1984) found diameter growth of yellow-poplar to be greater than that of oak in both 50 and 70 percent stocked plots 6 years after thinning a 29-year-old even-aged central hardwoods stand.

It is likely that most of the stand basal area growth (SBAG) and mean annual diameter growth (MADG) will occur in the first 4 to 5 years after thinning for both treatments. Treatment plots that contain a greater RD of yellow-poplar and perhaps black cherry will probably have greater increases in SBAG and MADG due to those species' ability to rapidly use available growing space. The greater growth increase will likely be more prevalent in the 60-percent treatments than in the 75 percent treatments. Whether the RD of dominant and codominant oaks will remain unchanged has not yet been determined. Previous studies found that oak height growth is competitive with black cherry height growth (Schuler 2006) but not that of yellow-poplar (Sonderman 1984).

These are baseline measurements of the first thinning in a series of thinnings that will be implemented in these stands at approximately 10-year intervals. This initial thinning has increased the oak component and increased mean diameter relative to the control. Therefore, it seems reasonable to assume there will continue to be a large oak component in these stands and that it can be enhanced in the next thinning treatment. In 10 years, each treatment plot will be near the A level or 100-percent stocking and ideal candidates for another thinning to further increase the oak component and mean diameter. Changes in the type of thinning and targeted residual species may be needed in future thinnings.

LITERATURE CITED

Abrams, M.D. and Nowacki, G.J. 1992. **Historical variation in fire, oak recruitment, and post-logging accelerated succession in central Pennsylvania.** Bulletin of the Torrey Botanical Club. 119: 19-28.

Brashears, M.B.; Fajvan, M.A.; Schuler, T.M. 2004. **An assessment of canopy stratification and tree species diversity following clearcutting in central Appalachian hardwoods.** Journal of Forest Science. 50(1): 61-62.

Chisman, H.H.; Schumacher, F.X. 1940. **On the tree-area ratio and certain of its applications.** Journal of Forestry. 38: 311-317.

Concilio, A.; Ma, S.; Li, Q. 2005. **Soil respiration response to prescribed burning and thinning in mixed-conifer and hardwood forests.** Canadian Journal of Forest Research. 35: 1586.

Dale, M. 1968. **Growth response from thinning young even-aged white oak stands.** Res. Pap. NE-112. Upper Darby, PA: U. S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 14 p.

Dale, M.; Sonderman, D.L. 1984. **Effect of thinning on growth and potential quality of young white oak croptrees.** Res. Pap. NE-539. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiement Station. 3 p.

Daniel, T.W.; Helms, J.A.; Baker, F.S. 1979. **Principles of silviculture.** New York, NY: McGraw-Hill Publishing. 420 p.

Fischer, B.C. 1987. **The regeneration response to clearcutting on the U.S. Forest Service Hoosier National Forest, United States Forest Service.** Report on file.

Gingrich, S.F. 1967. **Measuring and evaluating stocking and stand density in upland hardwood forests in the central states.** Journal of Forest Science. 13(1): 38-53.

Gingrich, S.F. 1970. **Effects of density, thinning, and species composition on the growth and yield of eastern hardwoods.** In: The silviculture of oaks and associated species. Res. Pap. NE-144. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 66 p.

Gingrich, S.F. 1971. **Management of young and intermediate stands of upland hardwoods.** Res. Pap. NE-195. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 21 p.

Hale, S.E. 2001. **The effect of thinning intensity on the below-canopy light environment in a Sitka spruce plantation.** Forest Ecology and Management 179(2003): 346 p.

Hilt, D.L. 1979. **Diameter growth of upland oaks after thinning.** Res. Pap. NE-437. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p.

Hilt, D.L.; Dale, M. 1997. **Effects of precommercial thinning on diameter growth in young central hardwood stands.** In: In: Hay, R.L.; Woods, F.W.; DeSelm, H., eds. Proceedings of the 6th central hardwood forest conference; 1996 February 24-26; Knoxville, TN. Knoxville, TN: University of Tennessee: 179-187.

Homoya, M.A.; Abrell, D.B.; Aldrich, J.D. 1985. **The natural regions of Indiana.** Proceedings Indiana Academy Science. 94: 245-268.

Jenkins, M.A.; Parker, G.R. 1998. **Composition and diversity of woody vegetation in silvicultural openings of southern Indiana forests.** Journal of Forest Ecology and Management. 109: 57-74.

Johnson, P.S.; Shifley, S.R.; Rogers, R. 2002. **The ecology and silviculture of oaks.** New York, NY: CABI Publishing.

Lamson, N.I.; Smith, C. 1978. **Response to crop tree release: sugar maple, red oak, black cherry, and yellow-poplar samplings in a 9 year old stand.** Res. Pap. NE-394. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Experiment Station. 8 p.

McCarthy, D.R.; Brown, K.J. 2006. **Soil respiration responses to topography, canopy cover, and prescribed burning in an oak-hickory forest in southeastern Ohio.** Journal of Forest Ecology and Management. 237(1).

Nowak, C.A.; Marquis, D.A. 1997. **Distribution of cut guides for thinning Allegheny hardwoods: a review.** Res. Note NE-362. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

Oliver, C.D.; Larson, B.C. 1996. **Forest stand dynamics.** New York, NY: Wiley Publishing.

Parker, G.R.; Merritt, C. 1995. **Regional silvilculture of the United States.** New York, NY: Wiley Publishing.

Roach, B.A.; Gingrich, S.F. 1968. **Even-aged silviculture for upland central hardwoods.** Agric. Handbk. 355. Washington, DC: U.S. Department of Agriculture Forest Service.

Schuler, T.M. 2006. **Crop tree release improves competitiveness of northern red oak growing in association with black cherry.** Northern Journal of Applied Forestry. 23(2): 77-82.

Shifley, S.R. 2004. **Oak growth and response to thinning.** In: Spetich, M.A., ed. 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: 198-205.

Smith, D.M.; Larson, B.C.; Kelty, M.J. 1997. **The practice of silviculture.** New York, NJ: Wiley Publishing.

Sonderman, D.L. 1984. **Quality response of 29 year old even-aged central hardwoods after thinning.** Res. Pap. NE-546. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiement Station.

Thibodeau, L.; Raymond, P.; Camire, C. 2000. **Impact of precommercial thinning in balsam fir stands on soil nitrogen dynamics, microbial biomass, decomposition, and foliar nutrition.** Canadian Journal of Forest Research. 30(2): 232-234.