United States
Department of
Agriculture

Forest Service

**Northern
Research Station**

General Technical
Report NRS-83

# Coopers Rock Crop Tree Demonstration Area—20-Year Results

**Arlyn W. Perkey**
**Gary W. Miller**
**David L. Feicht**

## Abstract

During the 1988/1989 dormant season, the Coopers Rock Crop Tree Demonstration Area was established in a 55-year-old central Appalachian hardwood forest in north-central West Virginia. After treatment, 89 northern red oak (*Quercus rubra* L.) and 147 yellow-poplar (*Liriodentron tulipifera* L.) crop trees were monitored for 20 years. This report summarizes the growth in diameter at breast height (d.b.h.) and crown development of crop trees from age 55 to 75 after they received various degrees of crown release resulting from crop tree management and traditional area-wide thinning. Annual d.b.h. growth response is presented to illustrate the year-to-year fluctuations in growth that occurred throughout the demonstration area. In general, d.b.h. growth response and crown expansion were related to the degree of crown release. Northern red oak exhibited a greater response in d.b.h. growth and crown expansion than did yellow-poplar over the 20-year study period.

## Cover photo

The Coopers Rock Crop Tree Demonstration Area was established at Coopers Rock State Forest through cooperation of the West Virginia Division of Forestry and the U.S. Forest Service's Northeastern Forest Experiment Station (now the Northern Research Station) and Northeastern Area State and Private Forestry. Clay Smith (left) and Arlyn Perkey welcome visitors at the entrance sign in 1990. Photo by U.S. Forest Service.

Manuscript received for publication 7 January 2011

Published by:

U.S. FOREST SERVICE
11 CAMPUS BLVD SUITE 200
NEWTOWN SQUARE PA 19073

June 2011

For additional copies:

U.S. Forest Service
Publications Distribution
359 Main Road
Delaware, OH 43015-8640
Fax: (740)368-0152
Email: nrspubs@fs.fed.us

Visit our homepage at: **http://www.nrs.fs.fed.us/**

## INTRODUCTION

During the 1988/1989 dormant season, the Coopers Rock Crop Tree Demonstration Area was established at Coopers Rock State Forest near Exit 15, U.S. Interstate 68 in eastern Monongalia County, West Virginia. The project is a cooperative effort of the state of West Virginia, Division of Forestry, and the U.S. Forest Service's Northeastern Area State and Private Forestry, and Northern Research Station (previously Northeastern Forest Experiment Station). The easily accessible location was chosen to encourage use by foresters, landowners, and others interested in the stewardship of family forests in the eastern hardwood region. Providing assistance to these clients was and is a goal for both of the supporting public agencies.

As this demonstration area was installed, the publication "Crop Tree Management in Eastern Hardwoods" had not yet been published, but its foundations were being developed (Perkey et al. 1994). Consequently, many of the terms and descriptive phrases used here are described in that publication. The concept of crop tree management (CTM) was emerging as an effective tool for improving communication between natural resource professionals and family forest landowners. The Coopers Rock Crop Tree Demonstration Area was the first of several demonstration areas established to provide on-the-ground examples of how CTM could be implemented to help accomplish the goals of family forest owners. It was also a means of transferring technology that was developed through many years of crop tree release research done by the U.S. Forest Service and universities.

***The Authors***

*ARLYN W. PERKEY is retired from the U.S. Forest Service's Northeastern Area State and Private Forestry at Morgantown, WV.*

*GARY W. MILLER is a research forester with the U.S. Forest Service's Northern Research Station at Morgantown, WV.*

*DAVID L. FEICHT is a retired forester from the U.S. Forest Service's Northern Research Station at Morgantown, WV.*

## DEMONSTRATION AREA

The approximately 10-acre demonstration area is subdivided into five plots, consisting of four treatment plots and a Control plot. Three separate CTM treatment plots and an Area-wide Thinning plot were oriented so four corners and sides adjoined. This layout provided a common viewpoint for visitors to observe each treatment from the four-corners location (Fig. 1). Because of limited space, the Control plot is not contiguous with the four treatment plots. It is located in the vicinity, with similar species composition, but on a more fertile growing site. Consequently, when treatment growth rates are contrasted with Control growth rates, any acceleration in growth evident on the treated plots is conservative. Furthermore, any acceleration of growth in treatment areas is clearly <u>not</u> because of more favorable site conditions. The four treatment plots are located on an upper, south-facing slope. The Control plot is located on a somewhat steeper mid-slope with a north-facing aspect. The Control plot is on a cooler, moister site, described as mesic Site Class 2 in "Using Diagnostic Plants To Evaluate Site Class" (Carvell and Perkey 1997). In contrast, the treatment plots are located on Site Class 4 and 5. In more traditional terms, the treated plots are located on site index 70 for northern red oak(*Quercus rubra* L.) (base age 50), and the Control plot is located on site index 80.

Photo by U.S. Forest Service

Figure 1.—This group of visitors in 1989 saw all four treatment plots from a single location. This perspective helps show the contrasting appearance of area-wide thinning with three different applications of crop tree management.

The lower third of the Control plot includes old pits that indicate disturbance by mining activity during the iron industry era described below. However, the height of the trees and the species composition of understory plants do not indicate any difference in site productivity from the rest of the Control plot. Basal area on the treated plots averaged 136 $ft^2$/ac, compared to 157 $ft^2$/ac on the Control plot (Table 1).

Coopers Rock State Forest, including this demonstration area, has a long history of human-caused disturbance (Rodd 1994). Five iron furnaces were established between 1798 and 1842. Iron ore, limestone, and charcoal were all obtained locally to make the industry viable. Supplying charcoal to the furnaces required heavy timber cutting, and subsequent wildfires were a common occurrence . The last of the five furnaces ceased operation in 1868. From 1912 to 1939, the area was heavily logged using railroads to transport timber to support sawmills. In 1936 the area was purchased by the state of West Virginia, and Coopers Rock State Forest was established. At that time, wildfires were controlled and the influence of periodic fires was greatly reduced.

The forest in the vicinity of the demonstration area is largely even-aged, with 1934 as the estimated stand-year-of-origin. The most common exception to the even-age status of the stand is the presence of a few scattered older, large white oaks. Some of them have fire scars at their base, affirming their presence dates back to the era when wildfires were common. However, there was no evidence of wildfires in the even-age stands on the demonstration area plots. The species composition in the overstory basal area is approximately 37 percent yellow-poplar (*Liriodentron tulipifera* L.) and 22 percent northern red oak with another 10 percent of other oak species (Table 2). The somewhat higher percentage of yellow-poplar in the Control plot reflects the better site conditions.

**Table 1.—Changes in stand basal area and relative density as a result of the treatments and subsequent 20-year growth, where BA = basal area, RD = relative density, and CT = Crop Tree**

| Treatment Objective | Plot | Initial | | Post-harvest | | After 20 Years | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | BA | RD | BA | RD | BA | BA growth | RD | RD growth |
| | | *ft²/ac* | *%* | *ft²/ac* | *%* | *ft²/ac* | *ft²/ac/yr* | *%* | *%/yr* |
| CTM Timber only (32 CT/ac ) | 2 | 130 | 84 | 43 | 35 | 105 | 3.1 | 66 | 1.6 |
| CTM Timber and Wildlife (25 CT/ac) | 1 | 132 | 78 | 60 | 48 | 147 | 4.4 | 91 | 2.2 |
| CTM Timber, Wildlife, and Aesthetics (21 CT/ac) | 4 | 148 | 106 | 83 | 68 | 145 | 3.1 | 81 | 0.7 |
| Area-wide Thinning | 3 | 133 | 99 | 83 | 68 | 147 | 3.2 | 88 | 1.0 |
| Control | 5 | 157 | 88 | 157 | 88 | 205 | 2.4 | 102 | 0.7 |

**Table 2.—Species composition by basal area in each plot in 2008**

| Treatment Objective | Plot | YP | NRO | BC | RM | CO | Other | Total |
|---|---|---|---|---|---|---|---|---|
| | | ---------- *percent* ---------- | | | | | | *ft²/ac* |
| CTM Timber Only (32 CT/ac ) | 2 | 36 | 28 | 16 | 10 | 8 | 2 | 105 |
| CTM Timber and Wildlife (25 CT/ac) | 1 | 39 | 22 | 9 | 11 | 8 | 11 | 147 |
| CTM Timber, Wildlife, and Aesthetics (21 CT/ac) | 4 | 33 | 14 | 2 | 26 | 8 | 17 | 145 |
| Area-wide Thinning | 3 | 31 | 27 | 1 | 14 | 14 | 13 | 147 |
| Control | 5 | 47 | 19 | 7 | 15 | 7 | 5 | 205 |
| Demo area average | All | 37 | 22 | 7 | 15 | 9 | 10 | 150 |

YP=yellow-poplar; NRO=northern red oak; BC=black cherry (*Prunus serotina* Ehrh.); RM=red maple (*Acer rubrum* L.); CO=chestnut oak (*Quercus montana* Willd.)

## METHODS

The CTM system focuses on favoring trees that promise to yield future forest benefits desired by the landowner. Crop trees are those that the landowner wishes to retain for many years because they can provide outstanding wildlife benefits, rapid increases in timber value, or intrinsic natural beauty. In many cases, the landowner is interested in producing multiple benefits, so crop trees may vary in terms of species or other attributes depending on how they meet the landowner's goals. Once the goals of the landowner are clear, the trees that help meet those goals can be identified as crop trees.

Clarifying the landowner's goals and identifying the crop trees are just initial steps in the CTM system. Most crop trees then receive a "crown-touching release," whereby adjacent trees whose crowns touch those of the crop trees are removed. After release, each crop tree is assigned a free-to-grow (FTG) rating of 0,1,2,3, or 4 based on the number of sides that are not touching the crowns of adjacent trees (Perkey and Wilkins 2001). Such a release treatment reduces competition for sunlight and soil nutrients around the crop tree (Fig. 2). The free-growing space around the crop tree allows it to grow faster and become more vigorous. The crop tree develops more foliage and a denser crown, thus enhancing its ability to gather sunlight and produce carbohydrates through photosynthesis. Belowground, the crop tree develops a larger root system so it can gather more moisture and nutrients from the soil. Released crop trees also become more resistant to insects, pathogens, and severe weather conditions than do their less vigorous neighbors.

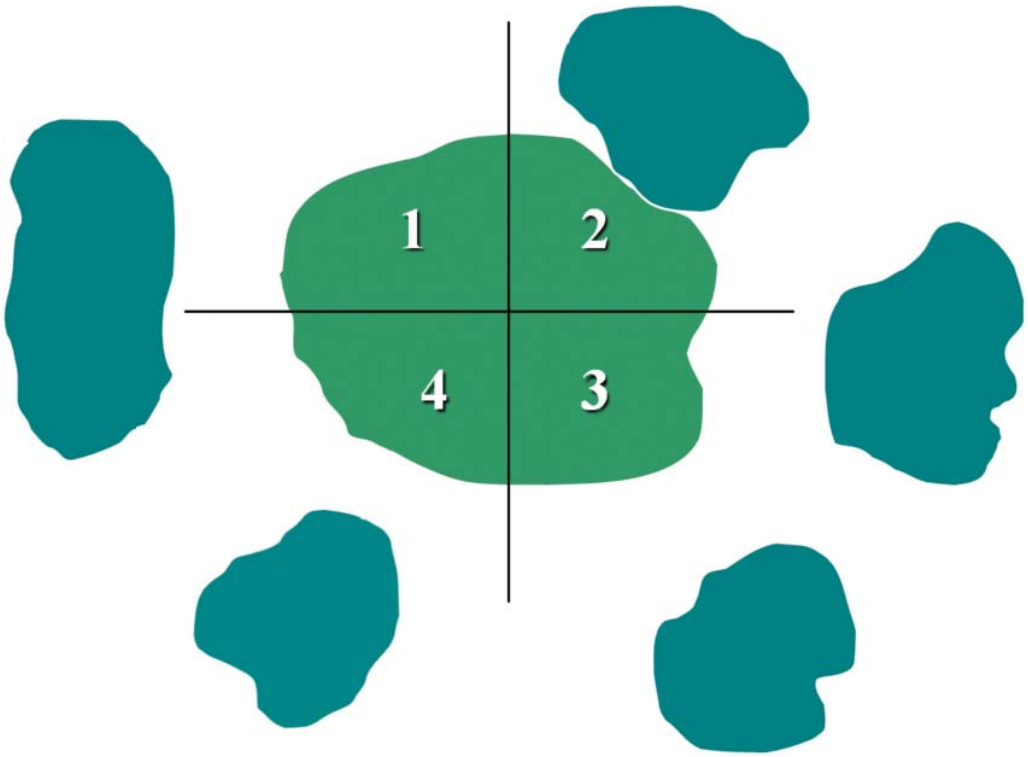


Figure 2.—The crop tree crown in the center of this illustration has been separated into four quadrants, or sides. A free-to-grow (FTG) rating is determined by the number of sides that are not touching the crowns of neighboring trees. The FTG rating for this tree equals 3 because competing trees on three sides have been removed.

Although the crown-touching release is a vital step in the CTM system, the two concepts are not synonymous. The crown-touching release is a specific treatment applied to most individual crop trees. (For exceptions, see definition of wildlife and aesthetic crop trees below). CTM is a much broader philosophy of forest management that takes into account the landowner's desires, the current and future condition of the forest, the quality of the growing site, the market for forest products, and possible effects of factors in the surrounding landscape. Additional details on applying the CTM system are available in three earlier references (Perkey et al. 1994, Perkey and Wilkins 2001, Miller et al. 2007). At this demonstration area, crop trees were selected based on three landowner goals: timber, wildlife, and aesthetics.

## Timber Crop Trees

Timber crop trees were those of better form and grade and with higher market value. They were also at low risk for being damaged in weather events. Timber crop trees had a minimum initial diameter at breast height (d.b.h.) of 9 inches, with relatively large, vigorous crowns in dominant or codominant crown classes. Ideal timber crop trees were free of epicormic branches on the lower 17 feet of the bole, contained less than 5 percent decay, and were free of low forks and severe sweep or crook. If there were not enough trees in the CTM plots to meet those standards, additional trees with the highest potential timber quality were selected from the remaining trees.

A key guideline used in the CTM plots was that no more than two crop tree crowns could be touching. The first preference was that every crop tree would be released from competing trees on all four sides of its crown. If two crop trees were adjoining, however, it was acceptable to select both as crop trees and remove competitors from around the perimeter of the two crop tree crowns. As a result, those two crop trees would have a crown-touching release on only three sides.

## Wildlife Crop Trees

Wildlife crop trees were those that produce preferred hard or soft mast or those that had existing dens or evidence of cavities that had the potential to develop dens for wildlife shelter. Trees with dominant and codominant crown classes were preferred. For wildlife food production, wildlife crop trees greater than 10 inches d.b.h. with large vigorous crowns were released. An attempt was made to find at least two crop trees per acre that provided shelter for wildlife. Wildlife crop trees that could produce both food and shelter were also released. Wildlife crop trees that were selected only to produce shelter were not released because the release treatment would not enhance their ability to provide wildlife shelter.

## Aesthetic Crop Trees

Aesthetic crop trees were those having either attractive flowers in the spring or brilliantly colored foliage in the fall. Crop trees were selected if they were unique or distinctive because of size, shape, form, or species. Aesthetic crop trees that were selected for their ability to produce attractive flowers or colorful foliage received a crown-touching release. Crop trees that were selected only because of their unique or distinctive size, shape, form, or species were not released because the release treatment would not enhance these attributes.

Photo by Arlyn Perkey, U.S. Forest Service (retired)

Figure 3.—Clearing a walking trail and publishing an accompanying Trail Guide helped explain contrasting treatments. In the CTM Timber Only plot, many visitors commented on the open appearance of the area, especially immediately after the release of crop trees.

In the three CTM plots, basal area and relative stand density were not used as guidelines to influence the selection of trees or the intensity of harvesting. However, these parameters were measured for comparative purposes since they are traditional measures of stand density for the professional forestry community. Six permanent point locations were established in each of the five plots, and fortunately, all points remained throughout the 20 years. These permanent variable-radius sample points provided continuity for measuring how the basal area and relative stand density changed over the 20 years.

The intensity of harvesting in the CTM plots was adjusted by changing the number of crop trees selected, but each crop tree was still released on three or four sides of the crown. Reducing the number of crop trees released reduces the intensity of cutting on a given area. Conversely, increasing the number of crop trees released increases the number of trees that are harvested and results in a more open-appearing residual stand. It is better to have fewer crop trees, fully released, than more crop trees, partially released.

The treatments in each plot were:

*CTM timber only***.** Enhancing the growth of timber crop trees was the only objective recognized in this plot. Northern red oak and yellow-poplar accounted for 94 percent of the crop trees. The treatment involved releasing 32 crop trees per acre on three or four sides of the crown. This plot received the heaviest harvest and had the most drastic change in appearance (Fig. 3).

*CTM timber and wildlife*. The intensity of cutting in this plot was adjusted downward by releasing only 25 crop trees per acre on three or four sides of the crown. This reduction in intensity of harvesting demonstrated a less abrupt change from the previously existing forest

Photo by Arlyn Perkey, U.S. Forest Service (retired)

Figure 4.—Directional felling was used to minimize damage to residual trees. In the CTM Timber, Wildlife, and Aesthetics plot, the lowest-intensity crop tree management treatment, avoiding residual trees while felling required specially trained personnel.

conditions. In addition, the species composition of selected crop trees was broadened to reflect wildlife as well as timber objectives. Species like northern red oak that could produce both timber and wildlife benefits were high priority candidates for selection as crop trees. Northern red oak and yellow-poplar made up 87 percent of the crop trees. Since there were more potential crop trees available than were selected for release, these additional trees (mostly yellow-poplar) were numbered and their growth was monitored, even though they were not intentionally released. Any release they did receive was incidental as a result of releasing the 25 crop trees per acre.

*CTM timber, wildlife, and aesthetics*. The intensity of cutting in this plot was likewise adjusted downward by releasing only 21 crop trees per acre on three or four sides of the crown (Fig. 4). The species composition of selected crop trees was additionally broadened to reflect aesthetic as well as wildlife and timber objectives. Northern red oak and yellow-poplar constituted 58 percent of the crop trees. Similar to the CTM Timber and Wildlife plot, there were more potential crop trees available than were selected for release. These additional trees (mostly yellow-poplar) were numbered and their growth was monitored, even though they were not intentionally released.

*Area-wide thinning***.** The treatment in this plot was an area-wide thinning to 83 $ft^2$/ac of basal area and 68 percent relative stand density. To achieve that reduction in basal area from the initial 133 $ft^2$/ac, one of every two pole-sized trees was cut and removed and one of every eight small sawtimber-size trees was cut and removed as recommended by Marquis et al. (1992)**.** The selection of trees to cut was based solely on timber as an objective; the poorest-quality timber trees were the highest priority for removal.

Although crop trees were not intentionally selected and released in this plot, potential timber crop trees were identified using the same criteria applied in the CTM plots. Their growth was then monitored so it could be compared to growth of trees that received crown-touching release treatments in the CTM plots and unreleased trees in the Control plot.

***Control.*** The Control plot received no treatment, but crop trees were selected using the timber objective and their growth was monitored for comparison with crop trees in the four treated plots.

All crop trees and comparison trees (more than 300 trees in all) were wired and tagged with numbers using a technique developed on the Fernow Experimental Forest near Parsons, WV, to accurately monitor tree growth (Lamson and Rosier 1984). Under this protocol, d.b.h. was measured annually in the dormant season and tree growth was monitored over a 20-year period.

A random sample of 10 northern red oak and 10 yellow-poplar crop trees or comparison trees was established in the Control, Area-wide Thinning, and a combination of the three CTM plots. These sample trees (30 northern red oaks and 30 yellow-poplars) provided data for interim reporting on how growth was progressing. All 60 of these sample trees survived the 20-year period. The growth of the sample subset was compared to the larger population of crop trees in the demonstration area, i.e., 236 crop trees.

Initial crown measurements were made on a random sample of 40 northern red oaks and 40 yellow-poplars in the treatment plots (10 of each species in each treated plot). Crown dimensions were measured in the four cardinal directions from the bole of the tree with a measurement taken at the drip edge of the crop or comparison tree crown, and a second measurement at the drip edge of the adjoining tree crown as a measure of the free-to-grow (FTG) distance. The average distance between the crop tree crown and the crowns of the adjacent trees measured in the four cardinal directions is the FTG distance. The same trees were measured 20 years later to provide a measure of crown expansion and reduction in FTG distance.

The harvesting was done by the U.S. Forest Service logging crew from the Fernow Experimental Forest during March and April 1989. This crew had experience doing crown-touching release treatments with the crop trees marked to leave. Cut trees in the CTM plots were not marked before harvest operations began, thus the logging crew felled and removed competing trees whose crowns were touching those of the crop trees. In the Area-wide Thinning plot, cut trees were marked as is customary for that practice. Skid roads were constructed around the perimeter of each treated plot. A Cat® D4 (Caterpillar, Inc., Peoria, IL) and an arch were used for skidding (Fig. 5). The crew "pulled cable" out to the felled trees from the skid roads to avoid equipment traffic in the interior of the treatment plots and to minimize damage to residual trees. When conditions were wet, logging was halted to avoid damage to roots and minimize soil compaction.

The corners of all plots and the six variable-radius points in each plot were marked with steel rebar. These points also served as camera points for before and after photographs. Numerous photos were taken throughout the area during the 20-year period.

Photo by Arlyn Perkey, U.S. Forest Service (retired)

Figure 5.—Harvested trees were pulled from the treatment plots with cable, and skidded out with a Cat® D4 and arch using perimeter roads to minimize damage to residual trees.

## DATA ANALYSIS

With only one plot assigned to each treatment, data from the demonstration area took the form of a case study whereby routine statistical analysis was not appropriate (Hurlbert 1984). Descriptive statistics, including means and standard errors, are provided to compare d.b.h. growth, crown radius growth, and reduction in FTG distance associated with crop trees in the various treatment plots over the 20-year period. The initial three comparisons focused on the response of crop trees among the treatments while keeping the species separate. First, the d.b.h. growth of crop trees in the three CTM plots was compared to that observed in the Control plots. Second, the d.b.h. growth of the 10 sample crop trees was compared to that of all crop trees in the CTM plots, Area-wide Thinning plot, and Control plot. A third within-species result compared the d.b.h. growth associated with different degrees of release, i.e., four-sided versus three-sided versus two-sided release. The final two comparisons focused on the response of northern red oak relative to that of yellow-poplar. First, d.b.h. growth of the two species was compared for different degrees of release in the treated plots. Second, crown measurements and FTG distances associated with the two species were compared in the CTM plots; only those crop trees that received a three- or four-sided release were analyzed.

## RESULTS

The variable-radius sample points in each plot were measured before and after the harvest treatments and then again after 20 years to measure changes in stand density. In general, the basal area harvested in the CTM plots increased as the number of crop trees increased (Table 1). In the CTM Timber, Wildlife, and Aesthetics plot, where 21 crop trees per acre were released, the harvest removed 44 percent of the basal area. In the CTM Timber Only plot, where 32 crop trees per acre were released, the harvest removed 67 percent of the basal area. Similar trends were observed for reductions in relative density. The harvest in the Area-wide Thinning

plot was prescribed to leave a residual relative density of 68 percent. Note that the CTM Timber, Wildlife, and Aesthetics plot, which had the lightest harvest of the CTM treatments, had the same residual relative density as that observed in the Area-wide Thinning treatment (Table 1). Although these treatments had similar effects on residual stand density, they differed in the degree of release around individual crop trees after treatment.

After treatment, the maximum basal area and relative density growth occurred in the CTM Timber and Wildlife plot, where 25 crop trees per acre were released (Table 1). The Control plot exhibited the lowest rate of basal area growth among the five plots, and lower relative density growth than all the treatment plots except the CTM Timber, Wildlife, and Aesthetics plot. Relative density calculations differ by species, whereas basal area calculations do not. Based on 20-year basal area growth, stand growth on all of the treated plots exceeded that observed in the Control plot.

In the CTM treatment plots, an effort was made to provide the crop trees with a three- or four-sided release, and the average FTG rating was 3.7 (SE=0.1) for northern red oak and 3.6 (SE=0.1) for yellow-poplar immediately after release (Tables 3 and 4). In some cases, two crop trees were located adjacent to each other, so they were released on only three sides. In most cases, however, crop trees were released on all four sides after the harvest operations. After 20 years, crop trees in the CTM plots were still free to grow on at least one side. In the Area-wide Thinning plot, the average FTG rating for both northern red oak (mean=2.4; SE=0.2) and yellow-poplar (mean=2.3; SE=0.2) indicated that crop trees in the CTM plots had about 50 percent more growing space around their crowns after treatment. The canopy in the Area-wide Thinning plot was nearly closed after 20 years, and the comparison crop trees had FTG ratings near zero in 2008. Comparison crop trees in the Control plot had FTG ratings near zero throughout the 20-year study period.

The degree of release provided to individual trees had a strong influence on d.b.h. growth response. Northern red oak crop trees in the CTM plots grew 6.5 (SE=0.2) inches in d.b.h. in 20 years, compared to only 4.1 inches (SE=0.3) for comparison trees in the Control plot (Table 3). Similarly, yellow-poplar crop trees in the CTM plots grew 5.0 (SE=0.1) inches in d.b.h. in 20 years, compared to only 3.3 (SE=0.1) inches for comparison trees in the Control plot (Table 4).

After a four-sided release to a northern red oak (crop tree no. 111) and a three-sided release to a black cherry (crop tree no. 106), the CTM Timber and Wildlife plot had a more open appearance than before treatment (Figs. 6 and 7). After 20 years, the northern red oak grew from 17.6 inches to 24.0 inches d.b.h., the black cherry grew from 14.6 inches to 16.9 inches d.b.h., and the plot once again had a closed appearance (Fig. 8).

A “random sample” of 10 northern red oak and yellow-poplar crop trees in the CTM, Area-wide Thinning, and Control plots was monitored to see how growth of a subset of trees would compare to the larger population of all trees in the study. The purpose was to determine whether a landowner could accurately monitor growth on a large number of crop trees by following a few sample trees. The growth of the sample trees was comparable to the larger population of crop trees for both species. For northern red oak, d.b.h. growth of the 10 sample

**Table 3.—Mean changes in free-to-grow (FTG) ratings and d.b.h. growth for northern red oak crop trees over a 20-year period. Standard errors are in parentheses.**

| Treatment Objective | Plot | N | 1988 FTG | 2008 FTG | 1988 d.b.h. | 2008 d.b.h. | 20-yr d.b.h. Growth |
|---|---|---|---|---|---|---|---|
| | | | | | ---------- *inches* | ---------- | |
| CTM Timber Only (32 CT/ac ) | 2 | 22 | 3.6 (0.1) | 1.8 (0.2) | 14.4 (0.5) | 20.9 (0.7) | 6.5 (0.3) |
| CTM Timber and Wildlife (25 CT/ac) | 1 | 15 | 3.8 (0.1) | 1.3 (0.2) | 14.9 (0.7) | 21.5 (0.9) | 6.6 (0.3) |
| CTM Timber, Wildlife, and Aesthetics (21 CT/ac) | 4 | 12 | 3.8 (0.1) | 0.6 (0.2) | 14.0 (0.7) | 20.2 (1.0) | 6.2 (0.4) |
| All CTM combined | 2,1,& 4 | 49 | 3.7 (0.1) | 1.4 (0.1) | 14.4 (0.3) | 20.9 (0.5) | 6.5 (0.2) |
| CTM sample | 2,1,& 4 | 10 | 3.8 (0.1) | 1.6 (0.3) | 15.2 (0.6) | 22.0 (0.9) | 6.8 (0.3) |
| Area-wide Thinning | 3 | 20 | 2.4 (0.2) | 0 (0.0) | 14.2 (0.6) | 19.4 (0.6) | 5.2 (0.3) |
| Area-wide Thinning sample | 3 | 10 | 2.9 (0.3) | 0 (0.0) | 15.1 (0.8) | 19.9 (1.0) | 4.8 (0.3) |
| Control | 5 | 20 | 0.1 (0.1) | 0 (0.0) | 15.4 (0.5) | 19.5 (0.8) | 4.1 (0.3) |
| Control sample | 5 | 10 | 0.1 (0.1) | 0 (0.0) | 15.2 (0.7) | 19.2 (1.0) | 4.0 (0.4) |

**Table 4.—Mean changes in free-to-grow (FTG) ratings and d.b.h. growth for yellow-poplar crop trees over a 20-year period. Standard errors are in parentheses.**

| Treatment Objective | Plot | N | 1988 FTG | 2008 FTG | 1988 d.b.h. | 2008 d.b.h. | 20-yr d.b.h. Growth |
|---|---|---|---|---|---|---|---|
| | | | | | ---------- *inches* | ---------- | |
| CTM Timber Only (32 CT/ac ) | 2 | 41 | 3.7 (0.1) | 2.1 (0.1) | 14.5 (0.4) | 19.5 (0.4) | 5.0 (0.1) |
| CTM Timber and Wildlife (25 CT/ac) | 1 | 23 | 3.5 (0.1) | 1.4 (0.2) | 15.9 (0.5) | 20.8 (0.6) | 4.9 (0.2) |
| CTM Timber, Wildlife, and Aesthetics (21 CT/ac) | 4 | 13 | 3.5 (0.1) | 0.4 (0.1) | 14.2 (0.4) | 19.6 (0.5) | 5.4 (0.2) |
| All CTM combined | 2,1,& 4 | 77 | 3.6 (0.1) | 1.6 (0.1) | 14.9 (0.3) | 19.9 (0.3) | 5.0 (0.1) |
| CTM sample | 2,1,& 4 | 10 | 3.8 (0.1) | 2.1 (0.3) | 15.4 (0.8) | 20.5 (0.7) | 5.1 (0.2) |
| Area-wide Thinning | 3 | 25 | 2.3 (0.2) | 0.3 (0.1) | 14.2 (0.5) | 17.8 (0.5) | 3.6 (0.2) |
| Area-wide Thinning sample | 3 | 10 | 3.0 (0.3) | 0.2 (0.1) | 15.6 (0.8) | 19.5 (0.9) | 3.9 (0.3) |
| Control | 5 | 45 | 0.2 (0.1) | 0 (0.0) | 16.9 (0.4) | 20.2 (0.4) | 3.3 (0.1) |
| Control sample | 5 | 10 | 0.5 (0.2) | 0 (0.0) | 15.3 (0.5) | 18.4 (0.5) | 3.1 (0.2) |

Photo by Arlyn Perkey, U.S. Forest Service (retired)

Figure 6.—In the CTM Timber and Wildlife plot in 1988, prior to release, the d.b.h. of northern red oak crop tree no. 111 (being measured) was 17.6 inches d.b.h.

Photo by Arlyn Perkey, U.S. Forest Service (retired)

Figure 7.—After a four-sided crown-touching release to tree no. 111, and a three-sided release to a 14.6-inch-d.b.h. black cherry crop tree (no. 106, flagged on right), the stand has a more "open" appearance.

trees differed from that of the larger population by 5, 8, and 3 percent for the CTM plots (n=49), Area-wide Thinning plots (n=20), and Control plots (n=20), respectively (Table 3). For yellow-poplar, the difference in d.b.h. growth between the 10 sample trees and the larger population was 2, 8, and 6 percent for the CTM plots (n=77), Area-wide Thinning plots (n=25), and Control plots (n=45), respectively (Table 4). The largest difference in growth

Photo by Arlyn Perkey, U.S. Forest Service (retired)

Figure 8.—After 20 years, northern red oak crop tree no. 111 has grown 6.4 inches to 24.0 inches d.b.h.. Black cherry tree no. 106 has grown 2.3 inches to 16.9 inches d.b.h. Crown expansion has reduced the free-to-grow rating on both trees to 1. Mid-story crowns have expanded and the stand has a more "closed" appearance.

occurred in the Area-wide Thinning plot, where there was also a notable difference in the average FTG rating between the sample trees and the larger population.

The annual d.b.h. measurements on the crop trees and comparison trees clarified how d.b.h. growth varied from year to year within a treatment plot and how d.b.h. growth was affected by the various treatments (Figs. 9 and 10). In general, northern red oak crop trees in the CTM plots grew faster than those in the Area-wide Thinning plot, and crop trees in all of the treated plots exhibited faster growth than that observed in the Control plot for most of the study period (Fig. 9). For yellow-poplar, d.b.h. growth was greatest from year to year in the CTM plots, but there were smaller differences between growth in the Area-wide Thinning and Control plots, particularly from year 10 to 20 (1998-2008) (Fig. 10). For both species, relatively faster d.b.h. growth was observed in 1993, 1995, 1998, and 2001, followed by relatively slower growth in 1994, 1996, 1999, and 2002. Such changes in annual d.b.h. growth, both positive and negative, appeared to be related to precipitation and unusual events because variations in growth exhibited similar year-to-year trends on all of the plots (Figs. 9 and 10). For example, the sharp decline in growth in 1994 and 1999 followed winter ice storms that caused significant damage to tree crowns, and precipitation in 1999 was well below normal. Although precipitation in 1994, 1996, and 2003 appears to be greater than normal, most of the growing-season rainfall occurred in heavy storms in late July and August. Much of the rainfall was lost to runoff and had little impact on tree growth in otherwise relatively dry years. Moreover, the Presidents' Day snowstorm in 2003 caused significant crown damage that further reduced growth that year. A similar decline in growth occurred in 2007. A wet snow in October 2006 occurred before the trees had dropped their leaves, and significant crown damage led to slower tree growth the following summer.

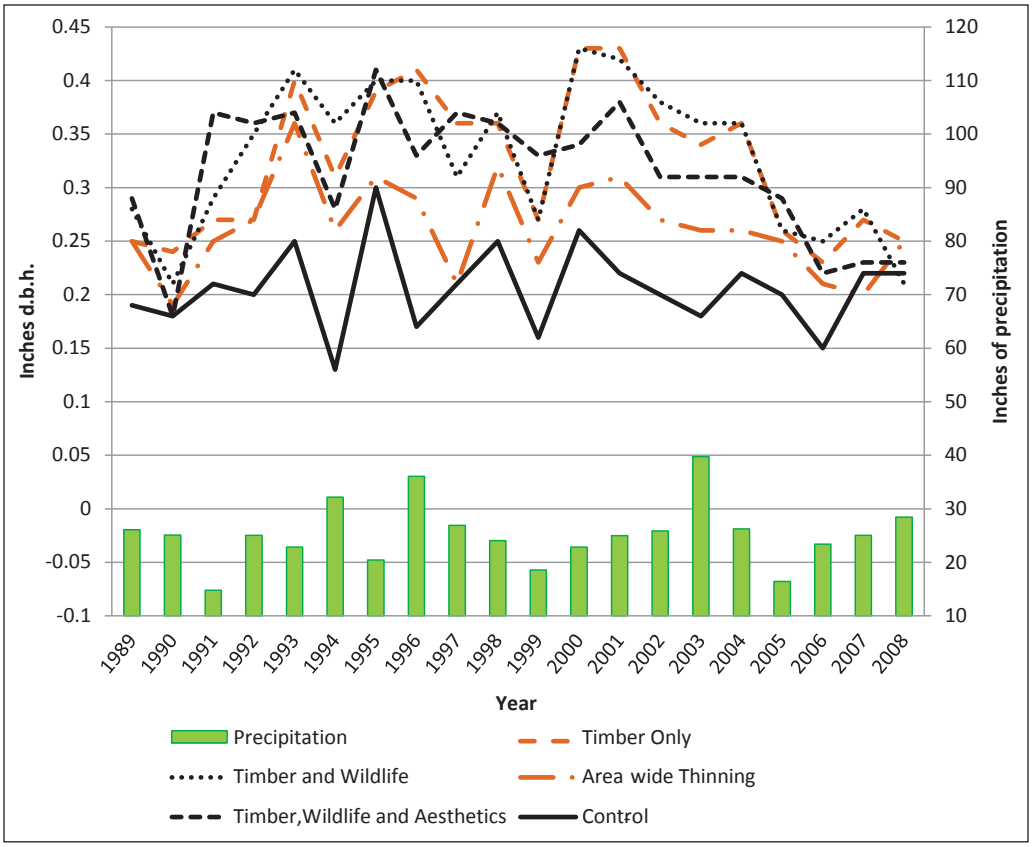


Figure 9.—Average annual d.b.h. growth for northern red oak and precipitation during the growing season from April through September.

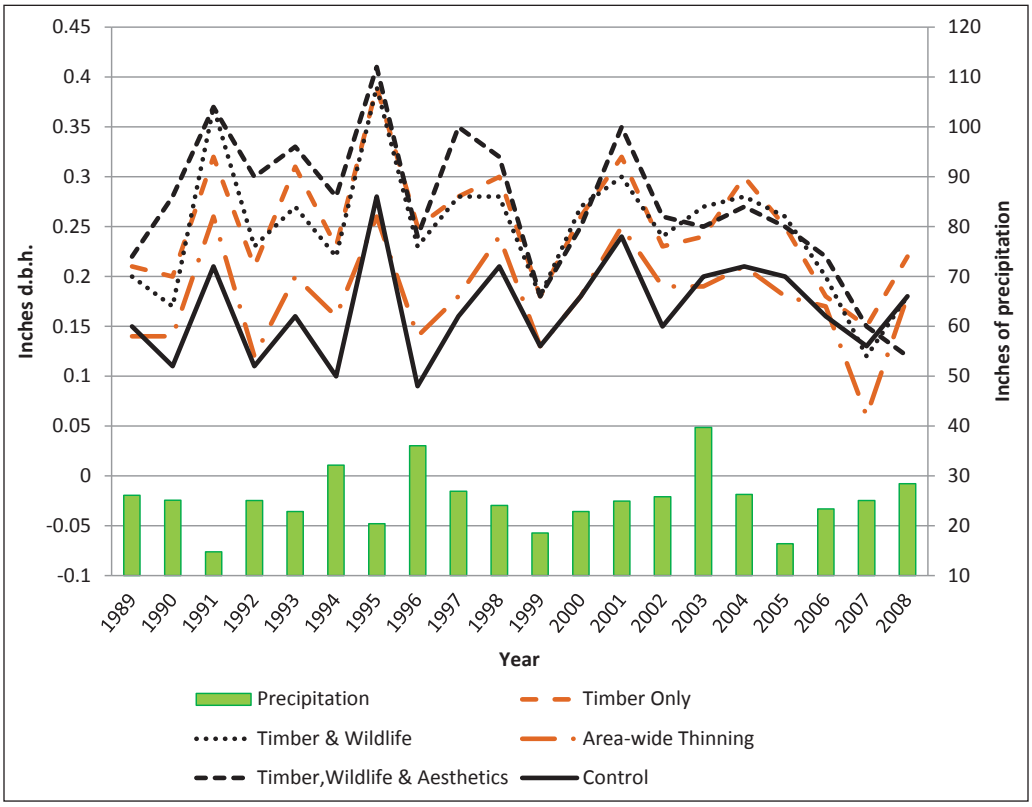


Figure 10.—Average annual d.b.h. growth for yellow-poplar and precipitation during the growing season from April through September.

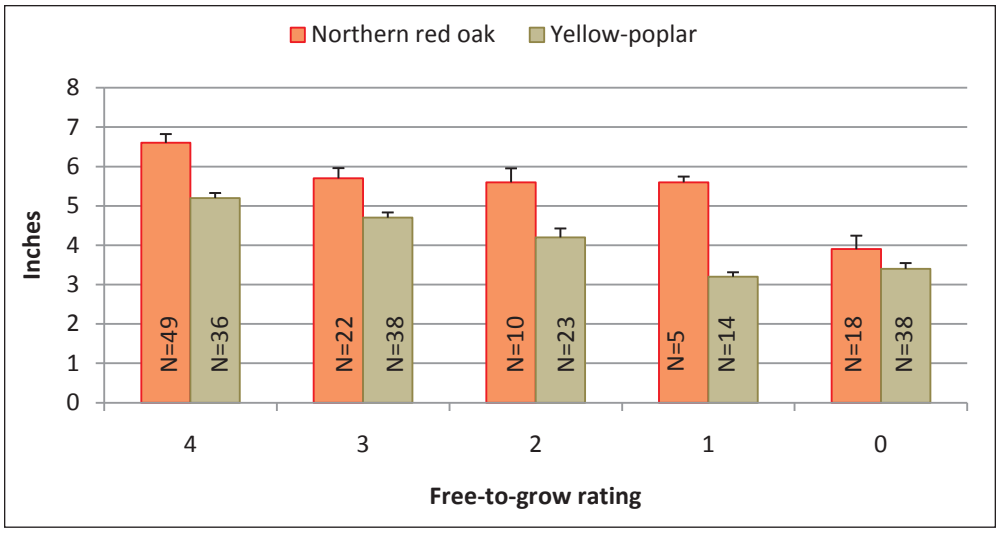


Figure 11.—Average 20-year d.b.h. growth by free-to-grow rating, with one standard error bar shown above each mean.

Faster growth in the treated plots was apparent in the first year after treatment, while the maximum increase in growth occurred 3 or 4 years later. Faster d.b.h. growth on the treated plots continued for many years, followed by a general decline in d.b.h. growth on the treated plots after 2004 (the 16$^{th}$ year after treatment) as crown expansion of the crop trees and other residual trees led to significant canopy closure. While crop trees on the CTM Timber Only plot had the highest FTG rating after 20 years, their d.b.h. growth declined in the last 5 years and appeared to be returning to pretreatment rates. In contrast, d.b.h. growth in the Control plot was consistent throughout the study period, averaging 0.21 (SE=0.02) inches per year for northern red oak and 0.17 (SE=0.01) inches per year for yellow-poplar.

The differences in d.b.h. growth between the CTM plots and the Area-wide Thinning plot can be explained by differences in the degree of crown release these treatments provided to the crop trees. For both northern red oak and yellow-poplar, faster d.b.h. growth in the CTM plots was associated with a greater FTG rating after treatment compared to the Area-wide Thinning plot (Tables 3 and 4). In the CTM plots, all of the crop trees received a three- or four-sided release. In the Area-wide Thinning plot, the majority of comparison crop trees received a two-sided release and only a few received a three-sided release. When the growth response of crop trees is stratified by degree of release, it is clear why growth was faster in the CTM plots (Fig. 11). For yellow-poplar, growth after a four-sided release exceeded that after a three-sided release and growth after a three-sided release exceeded that after a two-sided release. For northern red oak, growth after a four-sided release exceeded that observed after a three-sided release. Only 10 oaks received a two-sided release, and their growth was about the same as crop trees with a three-sided release. Note that for each FTG rating, d.b.h. growth of northern red oak exceeded that of yellow-poplar (Fig. 11).

Throughout the 55-year-old stand, yellow-poplar had grown faster than northern red oak for at least some of the time before the demonstration area was installed. This difference is reflected in the larger initial average d.b.h. of yellow-poplar compared to northern red oak in 1988 (Table 5) and was most pronounced on the Control plot. These results are consistent with the more cool and moist conditions on this north-facing slope. These more mesic conditions are

**Table 5.—D.b.h. growth, crown radius growth, and changes in free-to-grow (FTG) distance for crop trees released on three or four sides in the CTM plots. Standard errors are in parentheses.**

| Species | N | d.b.h. 1988 | d.b.h. 2008 | d.b.h. Growth | Crown radius 1988 | Crown radius 2008 | Crown radius growth | FTG distance 1988 | FTG distance 2008 | FTG distance reduction |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ------- *in.* ------- | | *in./yr* | ------- *ft* ------- | | *ft/yr* | ------- *ft* ------- | | *ft/yr* |
| NRO | 30 | 14.7 | 21.0 | 0.32 | 11.5 | 17.7 | 0.3 | 22.4 | 3.3 | - 1.0 |
| | | (0.5) | (0.7) | (0.01) | (0.5) | (0.7) | (0.02) | (1.8) | (0.6) | (0.1) |
| YP | 27 | 15.0 | 20.1 | 0.26 | 10.6 | 14.6 | 0.2 | 21.2 | 4.8 | - 0.8 |
| | | (0.5) | (0.4) | (0.01) | (0.5) | (0.5) | (0.02) | (1.4) | (0.7) | (0.1) |

**Table 6.—Species composition of the largest 20 percent of trees by d.b.h. within each treatment plot**

| Treatment | Plot(s) | N | 1988 species mix | | 2008 species mix | |
|---|---|---|---|---|---|---|
| All CTM combined | 2,1,& 4 | 24 | 13 YP | 11 RO | 10 YP | 14 RO |
| Area-wide Thinning | 3 | 7 | 4 YP | 3 RO | 2 YP | 5 RO |
| Control | 5 | 17 | 13 YP | 4 RO | 13 YP | 4 RO |

expected to favor yellow-poplar growth. However, the growth trend was reversed on all of the plots during the 20-year period from age 55 to 75. Northern red oak grew faster than yellow-poplar during our observation period. On the Control plot, yellow-poplar average d.b.h. still exceeded northern red oak average d.b.h. in 2008, but the difference had decreased from 1.5 inches in 1988 to 0.7 inches in 2008 (an 0.8-inch shift in favor of northern red oak). On the CTM plots, the size advantage shifted from yellow-poplar to northern red oak: yellow-poplar was 0.5 inches larger than northern red oak in 1988 but 0.9 inches smaller in 2008 (a 1.4-inch shift in favor of northern red oak). Similarly, on the Area-wide Thinning plots, northern red oak and yellow-poplar had identical average diameters in 1988, but northern red oak averaged 1.6 inches larger than yellow-poplar by 2008.

Crown measurements taken on 30 northern red oaks and 27 yellow-poplars in the CTM treatment plots provided information on crown radius growth of crop trees and changes in their degree of release. Initially, all of these crop trees were released on three or four sides. Immediately after the release treatment, the FTG distance around the crop tree crowns was larger for northern red oak, even though the oaks had a slightly larger crown radius compared to yellow-poplar (Table 5). The FTG distance declined faster around the northern red oak crop trees. The reduction in FTG distance over the 20-year study resulted from expansion of the crop tree crowns as well as expansion of the adjacent trees. About one-third of the reduction in FTG distance was due to expansion of the crop tree crowns. After release, both d.b.h. and crown radius of northern red oak crop trees grew approximately 23 percent and 50 percent faster, respectively, than those of yellow-poplar (Table 5).

Another result of the faster growth of northern red oak is a shift in species composition of the largest trees in the demonstration area (Table 6). The 1988 species mix of the largest 20 percent of the trees by d.b.h. was compared to the 2008 species mix of the same number of trees. In the CTM and Area-wide Thinning plots, the species mix of the largest trees has shifted in favor of northern red oak (Table 6). In the Control plot, it has remained the same.

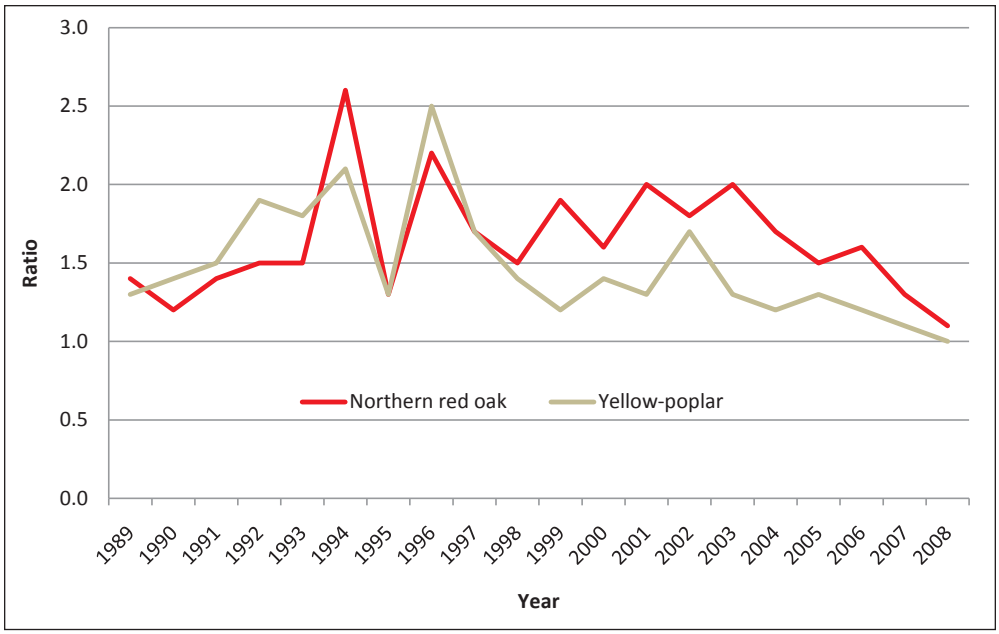


Figure 12.—Average basal area growth acceleration ratio.

Changes in both the average tree size and the number of trees of each species indicate that the treatments have accelerated this shift in size dominance from yellow-poplar to northern red oak. It is also interesting to note that in 1988 the two largest trees on the demonstration area were yellow-poplars that measured 22.5 inches d.b.h.. One was located in the Control plot and one was located on the CTM Timber and Wildlife plot. By 2008, the two largest trees on the demonstration area were northern red oaks, one measuring 30.3 inches d.b.h. in the CTM Timber and Wildlife plot, and the other measuring 29.0 inches d.b.h. in the CTM Timber Only plot.

While it was not an objective of this demonstration area to compare the dynamic relationship between yellow-poplar and northern red oak during the 20-year period, the growth measurements provide an opportunity to observe what has happened during this late-rotation stage of stand development (age 55 to 75). Annual basal area growth acceleration ratios were compared for northern red oak and yellow-poplar (Fig. 12). Average basal area growth rates for crop trees released on three or four sides in the CTM plots were divided by the average basal area growth rates in the Control plot for each year during the study period. An acceleration growth ratio greater than 1 indicates that the released crop trees grew faster than the unreleased comparison trees. Yellow-poplar growth acceleration ratios exceeded or matched those of northern red oak during the first 10 years after treatment. The reverse was true during the second 10 years. Note that the growth acceleration ratios of both species declined to equal nearly 1 at the end of the 20 years. A comparison of d.b.h. growth between northern red oak and yellow-poplar also illustrates how the oaks grew faster for the latter part of the study (Fig. 13).

The effect of maintaining crown release to accelerate the development of large trees in a shorter time is exemplified by two northern red oaks on the CTM Timber Only plot (Fig. 14). At age 55, one was 18.0 inches d.b.h. while an adjoining crop tree was 18.4 inches d.b.h.. In the first 55 years, they had attained almost the same size. In 1989, the larger tree was released on four

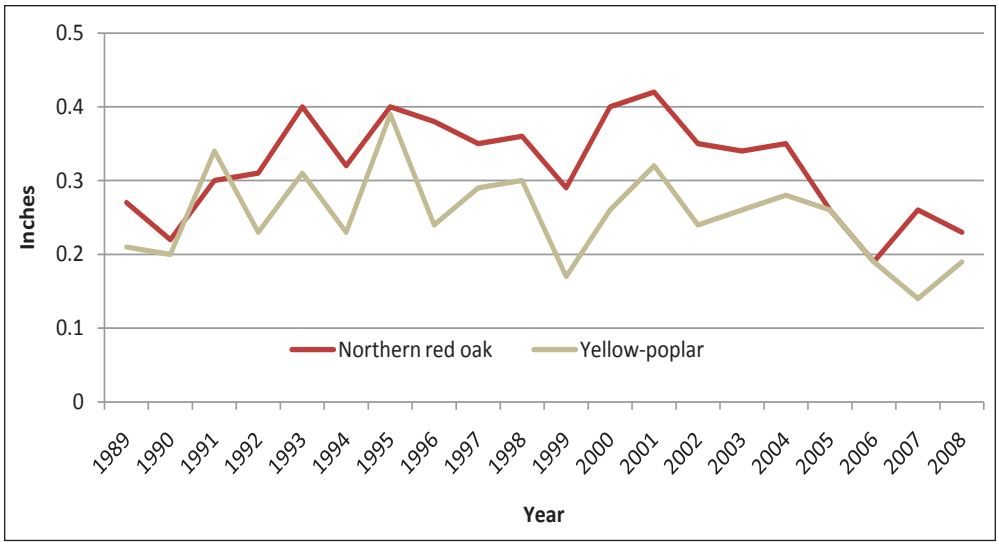


Figure 13.—Comparison of average annual d.b.h. growth of northern red oak (n=49) and yellow-poplar (n=77) for crop trees released on three or four sides in the CTM plots.

Photo by Arlyn Perkey, U.S. Forest Service (retired)

Figure 14.—Landowners interested in growing big trees in less time should maintain a high FTG rating around crop trees. The northern red oak in the foreground grew 10.6 inches d.b.h. as its FTG rating declined from 4 to 3 in 20 years. The northern red oak in the background grew only 6.9 inches d.b.h. as its FTG rating declined from 3 to 1 in 20 years. The two trees were nearly the same size in the CTM Timber Only plot when they were released in 1989.

sides and was still free to grow on three sides 20 years later. The smaller tree was released on three sides, but it was free to grow on one side after 20 years. The tree with more release grew 10.6 inches in d.b.h. in 20 years, while the tree with less release grew only 6.9 inches.

No crown ratio measurements were taken before or after release. However, photographs taken immediately after release and about 6 years later reveal the change in crown ratio following crown-touching release on northern red oak crop trees (Figs. 15 and 16). Two northern red oaks (tree nos. 59 and 60) began with a relatively small crown ratio immediately after treatment (Fig. 15) and then developed wider and deeper crowns by the sixth year after treatment (Fig. 16).

Damage to crop trees from logging wounds was measured in terms of area of exposed sapwood. Approximately 20 percent of the crop trees had some visible wounds, but most of those wounds were less than 50 $in^2$ in size . Such small wounds tend to form callous tissue and grow closed rapidly, especially on trees that have been released and are growing vigorously (Smith et al. 1994).

Assessing regeneration was not a goal for the demonstration area, so no regeneration measurements were taken at the beginning of the 20-year period. The approximately 8 acres of treatment area were surrounded by forest that had not experienced recent canopy-opening disturbance. Consequently, when sunlight penetrated the canopy of the treatment area, stimulating understory growth, it became an exceptional food source for deer. This disturbed "island" offered far more opportunity for deer browsing than did the surrounding closed-canopy woods.

Photo by Arlyn Perkey, U.S. Forest Service (retired)

Figure 15.—This photo of northern red oak trees nos. 59 and 60 was taken in October 1989 at the end of the first growing season following release.

Photo by Arlyn Perkey, U.S. Forest Service (retired)

Figure 16.—At the end of six additional growing seasons (October 1995), the live crowns of these same two trees were deeper, presumably producing more food and, consequently, more growth.

## DISCUSSION

After 20 years of measuring trees, monitoring tree growth, and showing the area to visitors, what has been learned?

In the first few years after the demonstration area was installed, some visitors to the CTM Timber Only plot commented that the harvest seemed too heavy to be considered a form of thinning (Perkey and Onken 2000). The plot contained 32 crop trees per acre that had been released on three or four sides and the residual basal area was only 43 $ft^2$/ac (Table 1). Indeed, the residual relative density was only 35 percent, somewhat more characteristic of a heavy shelterwood harvest to promote rapid growth of advanced reproduction or even a heavy diameter-limit harvest where all the merchantable trees were removed. However, the CTM Timber Only plot differed from other traditional harvests because the residual stand contained the largest and best quality trees available. The residual stand after traditional harvests would not have had as many high quality trees ready to expand their crowns and increase their growth. After 20 years, basal area had reached 105 $ft^2$/ac, and the basal area growth was 3.1 $ft^2$/ac/yr, similar to that of the Area-wide Thinning plot (Table 1). The most notable result in the CTM Timber Only plot was that it exhibited faster d.b.h. growth on a greater number of timber crop trees than any other plot on the demonstration area. The treatment in the CTM Timber Only plot may not have looked like a traditional thinning immediately after harvest, but it was indeed a "thinning": it concentrated growth on the best timber trees in the stand and it promoted a future stand that is now fully stocked with large, high quality northern red oak and yellow-poplar crop trees ready for final harvest.

Although the initial focus in applying CTM principles is on retaining crop trees for the future, some crop trees will eventually be harvested and some crop trees may be retained indefinitely. Crop trees in the demonstration area were retained for 20 years for the benefit of students and visitors, but in real-world applications of CTM, many of those crop trees can now be harvested to provide revenue for the landowner. Similar to other investments, timber crop trees eventually reach a financial maturity when it becomes advisable to harvest those trees and allow other trees with greater earning power to replace them. Even wildlife and/or aesthetic crop trees may be harvested in the future if their removal is necessary to enhance the growth of a new generation of crop trees for the future. Applying CTM principles involves both short-term and long-term planning; thus it is important to remember that many, if not all, crop trees may eventually be removed in later harvests.

In 1988, the 55-year-old forest in the demonstration area had just entered the commercially operable stage of development. Average potential crop tree size was 14 inches, with some trees as large as 22 inches d.b.h.. In stands like the demonstration area, the harvests in the Area-wide Thinning and the CTM Timber, Wildlife, and Aesthetics plots would not have been commercially operable because the harvested trees were too small and the total harvested volume was too low to attract a buyer. Instead of waiting until the stand grows more volume and can be thinned appropriately, the landowner often consents to some form of a diameter-limit harvest whereby all the trees large enough to yield a logging profit are removed (Fajvan et al. 1998). The diameter-limit harvest yields immediate revenue, but it also removes all of the best growing stock trees such that future stand development is sacrificed. A better alternative

would be to apply a harvest based on CTM principles so that modest revenue is possible, while retaining the best growing stock for the future. The CTM Timber Only and CTM Timber and Wildlife treatments produced enough harvest volume to be commercially operable in local markets because they removed more than half of the initial basal area. The short-term income would not be as great as with a traditional diameter-limit harvest, but the treatment would promote the largest and highest quality crop trees for a future harvest and provide the landowner with other non-timber woodland benefits.

Our observations over 20 years confirmed that the degree of crown release affected both the magnitude and duration of faster d.b.h. growth exhibited by individual crop trees (Figs. 9 and 10). Northern red oak and yellow-poplar crop trees were released on three or four sides in the CTM plots, while comparison trees in the Area-wide Thinning plots received less release and those in the Control plots received no release at all. Crop trees grew fastest on the CTM plots, followed by those in the Area-wide Thinning plot; those in the Control plots exhibited the slowest d.b.h. growth throughout the 20-year period (Tables 3 and 4). The difference in d.b.h. growth between crop trees in the treated plots and comparison trees in the Control plot was greatly reduced during the last 4 years, probably due to a reduction in free growing space around the released crop trees. Crown expansion of both crop trees and their neighbors gradually led to closure of canopy gaps around the crop trees and a return to growth rates similar to unreleased comparison trees (Table 5). A study of 12- to 16-year-old crop trees (Miller 2000) showed that those released on three or four sides required 8 years of growth to reach crown closure. In this 55-year-old stand, growth reduction associated with crown closure did not occur until about 16 years after release. This older stand, with larger crop trees and larger competitors, required about twice as much time to reflect growth reduction because of crown closure following treatment.

Although the release treatments generally accelerated the growth of crop trees, there were periods of lower d.b.h. growth due to abiotic factors such as crown damage from winter storms and irregular amounts of precipitation during the growing season (Figs. 9 and 10). Annual d.b.h. growth also fluctuated because of a biotic factor in the form of defoliation of yellow-poplar by the yellow-poplar weevil (*Odontopus calceatus* [Say] ) in 1993 and 1994. Defoliation averaged about 20 percent in those years, as evidenced by a drop in annual d.b.h. growth in 1994 (Fig. 10). Crop tree crowns recovered from the defoliation in 1995, and d.b.h. growth returned to that observed in years before the weevil defoliation.

The ups and downs observed in annual d.b.h. growth were consistent in all treatment plots in any given year. The average annual d.b.h. growth for northern red oak and yellow-poplar crop trees in each treatment plot is also presented in Tables 7 and 8. In general, crop trees with more free growing space exhibited greater d.b.h. growth than those with less growing space, even in years where annual d.b.h. growth fluctuated up or down. It was apparent from this observation that the crown-touching release was an effective means of maintaining faster d.b.h. growth, even in years when weather conditions or biotic factors might otherwise have had a more negative effect on growth.

Yellow-poplar crop trees were larger than northern red oak when the stand was 55 years old and the demonstration area was installed. Obviously, yellow-poplar had grown faster than

**Table 7.—Average annual d.b.h. growth of northern red oak crop trees by treatment. Standard errors are in parentheses.**

| Year | Timber Only (n=22) | Timber and Wildlife (n=15) | Timber, Wildlife, and Aesthetics (n=12) | All CTM (n=49) | Area-wide Thinning (n=20) | Control (n=20) |
|---|---|---|---|---|---|---|
| 1989 | .25 (.02) | .28 (.03) | .29 (.03) | .27 (.01) | .25 (.02) | .19 (.02) |
| 1990 | .24 (.03) | .21 (.02) | .18 (.03) | .21 (.02) | .19 (.02) | .18 (.02) |
| 1991 | .27 (.02) | .29 (.03) | .37 (.04) | .30 (.02) | .25 (.02) | .21 (.02) |
| 1992 | .27 (.02) | .35 (.03) | .36 (.03) | .32 (.02) | .27 (.02) | .20 (.02) |
| 1993 | .40 (.03) | .41 (.03) | .37 (.03) | .39 (.02) | .36 (.03) | .25 (.03) |
| 1994 | .31 (.03) | .36 (.04) | .28 (.03) | .32 (.02) | .26 (.02( | .13 (.02) |
| 1995 | .39 (.03) | .40 (.02) | .41 (.03) | .40 (.02) | .31 (.02) | .30 (.03) |
| 1996 | .41 (.02) | .40 (.02) | .33 (.03) | .39 (.01) | .29 (.02) | .17 (.02) |
| 1997 | .35 (.02) | .31 (.02) | .37 (.02) | .34 (.01) | .21 (.02) | .21 (.02) |
| 1998 | .36 (.03) | .37 (.03) | .36 (.04) | .36 (.02) | .32 (.03) | .25 (.03) |
| 1999 | .27 (.02) | .27 (.02) | .33 (.02) | .28 (.01) | .23 (.01) | .16 (.02) |
| 2000 | .43 (.03) | .43 (.03) | .34 (.03) | .41 (.02) | .30 (.02) | .26 (.02) |
| 2001 | .43 (.03) | .42 (.03) | .38 (.03) | .42 (.02) | .31 (.02) | .22 (.02) |
| 2002 | .36 (.03) | .38 (.03) | .31 (.03) | .35 (.02) | .27 (.03) | .20 (.02) |
| 2003 | .34 (.02) | .36 (.01) | .31 (.03) | .34 (.01) | .26 (.02) | .18 (.02) |
| 2004 | .36 (.03) | .36 (.01) | .31 (.03) | .35 (.02) | .26 (.02) | .22 (.02) |
| 2005 | .26 (.02) | .26 (.02) | .29 (.03) | .27 (.01) | .25 (.01) | .20 (.02) |
| 2006 | .23 (.03) | .25 (.03) | .22 (.03) | .23 (.02) | .21 (.02) | .15 (.02) |
| 2007 | .27 (.03) | .28 (.03) | .23 (.03) | .26 (.02) | .20 (.02) | .22 (.03) |
| 2008 | .25 (.02) | .21 (.03) | .23 (.02) | .23 (.01) | .25 (.03) | .22 (.02) |
| Sum | 6.45 | 6.60 | 6.27 | 6.44 | 5.25 | 4.12 |
| Mean | .32 | .33 | .31 | .32 | .26 | .21 |

Slight differences in average 20-year growth also shown in Table 3 are due to rounding.

northern red oak for at least some of that time. From age 55 to 75, however, northern red oak grew faster than yellow-poplar in both the Control and treated plots (Tables 3 and 4). Both species exhibited significantly faster d.b.h. growth after treatments were applied, but the increase in growth for northern red oak exceeded that of yellow-poplar (Fig. 13). Observations of comparison tree d.b.h. growth in the Control plot indicated that the forest in the general vicinity of the demonstration area had reached the stage in stand development described by Oliver (1977) during which the oaks begin to dominate neighboring species. The crown-touching release treatments, and to some degree the Area-wide Thinning, further enhanced the growth of northern red oak compared to yellow-poplar on this growing site. Forest managers could apply crown release treatments to the oak crop trees in mixed-species stands as a means of sustaining oaks in the upper canopy for many decades (Rentch et al. 2009). In addition, many family forest owners enjoy the aesthetic appearance of relatively large trees (Singer and Lorimer 1997). Family forest owners are likely to understand and accept CTM treatments that result in larger trees in a shorter period of time. Promoting large trees of both northern red oak and yellow-poplar on the same site further enhances the production of multiple woodland benefits such as timber value, wildlife food, and species diversity, and reduces the risk from insect and disease attack associated with single-species forests.

**Table 8.—Average annual d.b.h. growth of yellow-poplar crop trees by treatment. Standard errors are in parentheses.**

| Year | Timber Only (n=41) | Timber and Wildlife (n=23) | Timber, Wildlife, and Aesthetics (n=13) | All CTM (n=77) | Area-Wide Thinning (n=25) | Control (n=45) |
|---|---|---|---|---|---|---|
| 1989 | .21 (.01) | .20 (.02) | .22 (.02) | .21 (.01) | .14 (.01) | .15 (.01) |
| 1990 | .20 (.02) | .17 (.02) | .28 (.03) | .20 (.01) | .14 (.02) | .11 (.01) |
| 1991 | .32 (.02) | .37 (.02) | .37 (.02) | .34 (.01) | .26 (.02) | .21 (.01) |
| 1992 | .21 (.01) | .23 (.02) | .30 (.03) | .23 (.01) | .12 (.02) | .11 (.01) |
| 1993 | .31 (.01) | .27 (.02) | .33 (.02) | .31 (.01) | .20 (.01) | .16 (.01) |
| 1994 | .23 (.01) | .22 (.02) | .28 (.02) | .23 (.01) | .16 (.01) | .10 (.01) |
| 1995 | .39 (.01) | .39 (.02) | .41 (.02) | .39 (.01) | .26 (.02) | .28 (.02) |
| 1996 | .25 (.01) | .23 (.02) | .24 (.03) | .24 (.01) | .14 (.01) | .09 (.01) |
| 1997 | .28 (.01) | .28 (.02) | .35 (.02) | .29 (.01) | .18 (.01) | .16 (.02) |
| 1998 | .30 (.01) | .28 (.02) | .32 (.03) | .29 (.01) | .24 (.01) | .21 (.01) |
| 1999 | .18 (.01) | .18 (.02) | .18 (.02) | .18 (.01) | .13 (.01) | .13 (.01) |
| 2000 | .26 (.01) | .27 (.02) | .25 (.02) | .26 (.01) | .18 (.01) | .18 (.01) |
| 2001 | .32 (.01) | .30 (.02) | .35 (.02) | .32 (.01) | .25 (.02) | .24 (.01) |
| 2002 | .23 (.01) | .24 (.02) | .26 (.02) | .24 (.01) | .19 (.02) | .15 (.01) |
| 2003 | .24 (.01) | .27 (.02) | .25 (.02) | .25 (.01) | .19 (.02) | .20 (.01) |
| 2004 | .30 (.01) | .28 (.02) | .27 (.02) | .29 (.01) | .21 (.01) | .21 (.01) |
| 2005 | .25 (.01) | .26 (.02) | .25 (.03) | .25 (.01) | .18 (.01) | .20 (.01) |
| 2006 | .18 (.01) | .20 (.02) | .22 (.02) | .19 (.01) | .17 (.01) | .16 (.01) |
| 2007 | .15 (.01) | .12 (.02) | .15 (.01) | .14 (.01) | .06 (.01) | .13 (.02) |
| 2008 | .22 (.01) | .18 (.02) | .12 (.03) | .19 (.01) | .18 (.02) | .18 (.02) |
| Sum | 5.03 | 4.94 | 5.40 | 5.04 | 3.58 | 3.36 |
| Mean | .25 | .25 | .27 | .25 | .18 | .17 |

Slight differences in average 20-year growth also shown in Table 4 are due to rounding.

Hard mast production was not monitored during the 20-year period. Consequently, we do not have a direct measurement to show an increase in seed production beneficial to wildlife. However, acorns are grown on the perimeter of live crowns where the vegetation is exposed to direct sunlight. The expansion of live crown area for species like northern red oak indicates that released crop trees will be able to produce greater quantities of food for wildlife (Figs. 14 and 15). During the 20-year period, northern red oak crowns that received a crown-touching release on three or four sides, expanded their crown area by 2.4 times while yellow-poplar expanded their crowns by 1.9 times (Table 5). This greater rate of crown area expansion for the oaks means that wildlife species will likely benefit from greater acorn production in the future.

Some existing wildlife dens in the CTM Timber Only plot and the Area-wide Thinning plot were lost when trees containing them were harvested, while existing den trees in the CTM Timber and Wildlife plot were retained because they were explicitly marked as crop trees. When wildlife shelter is important for meeting landowner goals, the criteria for selecting crop trees should include potential den trees so that they are identified and protected during the commercial harvest operation. Although den trees may not receive a crown-touching release, as is the case for timber crop trees, they should be marked with paint like the other crop trees so that loggers can avoid damaging them.

Photo by U.S. Forest Service

Figure 17.—This demonstration area provides an opportunity for family forest owners and foresters who serve them to see how alternative treatments might appear.

Some crop trees that exhibited attractive fall foliage were retained and their crowns were released to promote crown expansion. Crown expansion was not measured for aesthetic crop trees, but subjective visual observations during the fall in the CTM Timber, Wildlife, and Aesthetics plot confirmed that the aesthetic crop trees survived and produced more attractive fall foliage than before the CTM treatment. In cases where the forest manager wishes to enhance the attractiveness of a landscape viewed from a fixed observation point, CTM can be applied to promote a desired mix of species and their associated fall colors.

The abundance of white-tailed deer (*Odocoileus virginianus*) in the surrounding area had a profound influence on the species composition of advanced reproduction that developed in the CTM Timber Only and CTM Timber and Wildlife plots. The harvests were relatively heavy in these plots, with residual basal areas equal to 43 $ft^2$/ac and 60 $ft^2$/ac, respectively. Such heavy disturbance to the overstory tends to increase the availability of sunlight on the forest floor, stimulating the germination of stored seed and enhancing the growth of existing seedlings. While establishing or releasing regeneration was not a goal at the demonstration area, an important observation was noted. Because browse was more available in the harvested plots than in the surrounding forest, browsing pressure by white-tailed deer was heavy. Stump sprouts of preferred species like northern red oak, yellow-poplar, and red maple were repeatedly nipped back to the stump until it died. Species lower on the browse preference list, like black cherry, had favorable conditions to develop advanced reproduction on the forest floor. Even though black cherry occupied only 7 percent of the initial overstory basal area, the advanced reproduction in the understory was eventually dominated by black cherry seedlings and saplings. Additional treatments may be needed before the overstory is removed to prepare for successful regeneration of other desired species (Brose et al. 2008).

One lesson from the CTM demonstration area was quite valuable: the show-and-tell example plots made complex ideas associated with forestry and ecology easy to communicate to visitors (Fig. 17). The CTM concept was easy for landowners and forest management professionals to understand because they could readily grasp the effectiveness of identifying and promoting the development of individual crop trees. Instead of trying to absorb the complexities of tending hundreds of trees per acre, visitors saw firsthand how the same job could be accomplished by applying a simple crown-touching release to a fairly small number of trees per acre. The demonstration area also provided visible examples of crop trees that provide specific benefits such as timber value, wildlife food, wildlife shelter, spring flowers, or beautiful fall colors. In some cases, an individual crop tree offered multiple desired benefits. The layout of the demonstration area further provided an enjoyable, informative "classroom." Visitors to the demonstration area were able to see several variations of CTM and Area-wide Thinning within a short walking distance, thus allowing visual reinforcement of key concepts and plenty of time for questions and answers within a 1- to 2-hour visit. Many visitors have returned to the demonstration area for a self-guided tour using the Trail Guide (Perkey and Wilkins 2005) to enhance their understanding of CTM concepts during different seasons of the year. Songbirds in spring, lush foliage in summer, brilliant color in autumn, and shining snow in winter add to a more complete understanding of how CTM can enhance a family forest.

## ACKNOWLEDGMENTS

This 22-year project has benefited from the efforts of many individuals. First, the late Clay Smith, long-time co-worker and former Northeastern Forest Experiment Station Project Leader, was a key partner from the beginning. Much of the success of this project is attributable to his wisdom, experience, and way of bringing a variety of people together to accomplish a task. Other early participants from the Fernow Experimental Forest include Robert Rosier, Richard Hovatter, Brian Simpson, the late Roy Poling, the late Lee Long, and Alan Myers. More recent participants from the Northern Research Station include Regis Young, John Juracko, Drew Cantis, and Toni Jones. From the Northeastern Area State and Private Forestry, we thank Brenda Wilkins (retired), Amy Hill, Roxane Palone (retired), Nancy Lough (retired), Helen Wassick, Frank Cromer, and Karen Sykes. From the West Virginia Division of Forestry, we thank Andrew Dick, Rodger Ozburn, and Lowell McPherson (retired). From West Virginia State Parks, we thank Al Kerns and his staff. From West Virginia University, we thank graduate student Jonathan Marden. We also thank Jeff Ward, David Mercker, and John Stanovick for helpful review comments.

## LITERATURE CITED

Brose, P.H.; Gottschalk, K.W.; Horsley, S.B.; Knopp, P.D.; Kochenderfer, J.N.; McGuinness, B.J.; Miller, G.W.; Ristau, T.E.; Stoleson, S.H.; Stout, S.L. 2008. **Prescribing regeneration treatments for mixed-oak forests in the mid-Atlantic region**. Gen. Tech. Rep. NRS-33. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 90 p.

Carvell, K.L.; Perkey, A.W. 1997. **Using diagnostic plants to evaluate site class.** NA-TP-03-97. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Northeastern Area, State and Private Forestry. 28 p.

Fajvan, M.A.; Grushecky, S.T.; Hassler, C.C. 1998. **The effects of harvesting practices on West Virginia's wood supply.** Journal of Forestry. 98(5): 33-39.

Hurlbert, S.H. 1984. **Pseudoreplication and the design of ecological field experiments**. Ecological Monographs. 54(2): 187-211.

Lamson, N.I.; Rosier, R.L. 1984. **Wires for long-term identification of trees.** Journal of Forestry. 82: 110-111.

Marquis, D.A.; Ernst, R.L.; Stout, S.L. 1992. **Prescribing silvicultural treatments in hardwood stands of the Alleghenies (revised).** Gen. Tech. Rep. NE-96. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 101 p.

Miller, G.W. 2000. **Effect of crown growing space on the development of young hardwood crop trees.** Northern Journal of Applied Forestry. 17(1): 25-35.

Miller, G.W.; Stringer, J.W.; Mercker, D.C. 2007. **Technical guide to crop tree release in hardwood forests.** Southern Regional Extension Forestry publication SREF-FM-011. [Place of publication unknown]: Southern Regional Extension Forestry. Available at http://www.sref.info/resources/publications/ 24 p. (Accessed June 28, 2011).

Oliver, C.D. 1977. **Reconstruction of a mixed-species forest in central New England**. Ecology. 58(3): 562-572.

Perkey, A.W.; Onken, A. 2000. **A decade at a crop tree demonstration area.** Forest Management Update. 20: 1-13.

Perkey, A.W.; Wilkins, B.L. 2001. **Crop tree field guide-selecting and managing crop trees in the central Appalachians.** NA-TP-10-01, Morgantown, WV: U.S. Department of Agriculture, Forest Service, Northeastern Area, State and Private Forestry. 140 p.

Perkey, A.W.; Wilkins, B.L. 2005. **Trail guide—Coopers Rock Crop Tree Demonstration Area.** NA-FR-01-05. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Northeastern Area, State and Private Forestry. 36 p.

Perkey, A.W.; Wilkins, B.L.; Smith, H.C. 1994. **Crop tree management in eastern hardwoods.** NA-TP-19-93. Morgantown, WV: Northeastern Area, State and Private Forestry. 112 p.

Rentch, J.S.; Miller, G.W.; Gottschalk, K.W. 2009. **Crown class dynamics of oaks, yellow-poplar, and red maple after commercial thinning in Appalachian hardwoods: 20-year results.** Northern Journal of Applied Forestry. 26(4): 156-163.

Rodd, J.S. 1994. **A guide to Coopers Rock State Forest-featuring trail guides, area history & ecology, & more.** Moatsville, WV: Barn Echo Press. 80 p.

Singer, M.T.; Lorimer, C.G. 1997. **Crown release as a potential old-growth restoration approach in northern hardwoods.** Canadian Journal of Forest Research. 27: 1222-1232.

Smith, H. C.; Miller, G. W.; Schuler, T. M. 1994. **Closure of logging wounds after 10 years.** Res. Pap. NE-692. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

Perkey, Arlyn W.; Miller, Gary W.; Feicht, David L. 2011. **Coopers Rock Crop Tree Demonstration Area—20-year results.** Gen. Tech. Rep. NRS-83. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 28 p.

During the 1988/1989 dormant season, the Coopers Rock Crop Tree Demonstration Area was established in a 55-year-old central Appalachian hardwood forest in north-central West Virginia. After treatment, 89 northern red oak (*Quercus rubra* L.) and 147 yellow-poplar (*Liriodentron tulipifera* L.) crop trees were monitored for 20 years. This report summarizes the growth in diameter at breast height (d.b.h.) and crown development of crop trees from age 55 to 75 after they received various degrees of crown release resulting from crop tree management and traditional area-wide thinning. Annual d.b.h. growth response is presented to illustrate the year-to-year fluctuations in growth that occurred throughout the demonstration area. In general, d.b.h. growth response and crown expansion were related to the degree of crown release. Northern red oak exhibited a greater response in d.b.h. growth and crown expansion than did yellow-poplar over the 20-year study period.

KEY WORDS: crop tree management, northern red oak, yellow-poplar, crown expansion, growth, central Appalachian

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternate means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202)720-2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, S.W., Washington, DC 20250-9410, or call (800)795-3272 (voice) or (202)720-6382 (TDD). USDA is an equal opportunity provider and employer.

Printed on Recycled Paper

*www.nrs.fs.fed.us*