# Composition and Development of Reproduction in Two-Age Appalachian Hardwood Stands: 20-Year Results

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**Abstract**—*In the early 1980s, silviculturists with the Northeastern Research Station and Monongahela National Forest envisioned that managing some Appalachian hardwood stands to promote two-age structures would be part of an effective strategy for managing multi-use forests. Two-age stands provided the light and seedbed conditions necessary for regenerating numerous desirable hardwood species and maintaining species diversity. The residual overstory trees also served to maintain vertical structure, mast production, wildlife habitat, and esthetic quality in visually sensitive areas. This paper examines the composition and development of approximately 20-year-old reproduction growing beneath 100-year-old residual overstory trees in two-age central Appalachian hardwood stands. After 20 years, the crowns of the residual overstory trees had expanded by nearly 80 percent and collectively covered almost half of the stand area. Desirable shade-intolerant species such as black cherry, northern red oak, and yellow-poplar in the new age class had remained competitive only in areas located between the crowns of the residual overstory trees. The areas located beneath the residual overstory trees were occupied by tolerant species such as sugar maple, red maple, and American beech. Data indicated that the residual overstory trees had a strong influence on the development and long-term species composition of reproduction. Practical alternatives for planning and implementing two-age management systems are discussed.*

## Introduction

Clearcut harvesting became a common silvicultural practice in eastern hardwoods nearly 40 years ago for several reasons. Some were based on the need to facilitate the management of large forested areas, while others were based on the need to promote the biological conditions necessary for regenerating a wide range of hardwood species. For management objectives, clearcut harvesting resulted in new stands with even-aged structures, which allowed forest planners to manage mosaics of stands and balance the age distribution of large industrial and public forests, thus sustaining the long-term yield of a variety of woodland benefits. In addition, simultaneous removal of all merchantable stems promoted harvesting and marketing economies of scale that were advantageous to both buyer and seller of wood products. For biological objectives, the open conditions following removal of the overstory created the sunlight and seedbed conditions that led to prolific regeneration of the full range of native tree species from stored seed, advanced seedlings, and sprouts. A diverse mix of highly valuable hardwood species for both wildlife and timber developed rapidly as young trees responded to excess growing space freed by the harvest operations. Silviculturists understood that disturbance patterns greatly affect the regeneration processes among tree species. Scientific evidence had shown that repeated partial harvests

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promoted uneven-age stand structures, undesirable shifts in species composition toward shade-tolerant species, and over time, a general loss of tree species diversity (Trimble 1973). Alternatively, clearcut harvesting produced new even-age stands that contained numerous tree species, regardless of shade tolerance. This response allowed forest managers to achieve the critical management objective of replacing harvested trees with young vigorous trees of the same species, thus maintaining species diversity. In the 1960s, clearcut harvesting became a common harvesting practice because it was an effective way to meet multiple management objectives within the biological constraints of the hardwood forest.

Along the way, public opposition to the appearance of forest stands immediately after clearcut harvests led forest managers and scientists to seek an alternative practice that was equally effective in sustaining desirable species composition but less offensive to the eye. The cooperative effort between the Monongahela National Forest and the Northeastern Research Station to study the effects of two-age stand structures began in the 1970s and continues today (Miller and others 1997b).

From 1979 to 1984, a form of deferment cutting (Smith and others 1989) was applied in mature, second-growth Appalachian hardwood forests to create experimental stands with two-aged structures. Deferment cutting (also called clearcutting-with-reserves, shelterwood-with-reserves, or irregular shelterwood) entails leaving 10 to 20 residual overstory trees per acre and cutting all other stems ≥1.0-inch diameter at breast height (DBH) (Smith and Miller 1991a). The open conditions following deferment cutting are similar to those exhibited after clearcut harvesting, thus providing adequate sunlight and seedbed conditions for numerous hardwood species to regenerate naturally (Johnson and others 1998). Several previous reports on the experimental two-age stands documented the initial response of the residual overstory trees (Smith and Miller 1991b; Smith and others 1994; Miller and others 1995; Miller 1996), the early development of reproduction (Miller and Schuler 1995; Miller and others 1997a), and the impact of vertical structure on insect and songbird habitat (Duguay and others 2000).

Many years have elapsed since the experimental stands were created, and there is now an opportunity to further evaluate the interaction of residual overstory trees and reproduction in two-age stands. As these stands continue to develop, several key silvicultural questions remain. How fast does the stand area covered by the crowns of the residual overstory trees expand over time? How do residual overstory trees influence the development of reproduction? How can silvicultural prescriptions applied to promote two-age stands be improved? Although the results presented here are relatively limited in scope, they shed light on important issues that silviculturists need to consider when applying two-age management systems in hardwood forests.

## Study Areas

The four study areas are located on the Monongahela National Forest in north-central West Virginia. All stands were on northern red oak site index 70 to 80 (base age 50 years). The average soil depth exceeds 3 feet, and annual precipitation averages 59 inches distributed throughout the year. The soil series for each stand were described as follows: Riffle Creek (Berks channery silt loam), Fish Trough (Calvin channery silt loam), Red

House (Dekalb stony loam), and Shavers Fork (Berks channery silt loam), all characteristic of loamy-skeletal, mixed, mesic Typic Dystrochrepts (USDA Soil Conservation Service 1967; 1982).

When the study began, the study areas were 75- to 80-year-old, second-growth Appalachian hardwood stands that became established after heavy commercial harvests that occurred in the early 1900s. Periodic fire was common throughout the region from 1910 to 1930 as the stands became established. Chestnut blight was also a common disturbance during the 1930s, but no other major disturbances occurred until deferment cutting was applied in 1979 to 1984 to begin studying the two-aged management system. Stand area ranged from 10 to 15 acres.

## Methods

In each stand, deferment cutting (Smith and others 1989) was applied to regenerate a new age class of trees and promote the development of a two-age stand structure. The boles of merchantable cut-trees were removed, while their tops and all non-merchantable cut-trees were left on the site. Residual trees were selected with preference for codominant, high-quality northern red oak (*Quercus rubra*) followed by yellow-poplar (*Liriodendron tulipifera*) and black cherry (*Prunus serotina*). Marking guidelines also called for leaving 15 to 20 overstory trees/acre with residual basal area less than 30 $ft^2$/acre, thus promoting suitable light conditions for vigorous natural regeneration of a diverse mix of hardwood species. The residual overstory trees were tagged for long-term monitoring. DBH, total height, and crown radius of residual overstory trees were measured immediately after the logging operations were completed.

Reproduction data were obtained before logging and at 5-year intervals after logging from 170 permanent sample points located along systematic grids throughout the four study areas. Small reproduction, defined as woody stems ≥12 inches tall and <1.0 inch DBH, was tallied on 0.001-acre circular plots. Large reproduction, defined as woody stems ≥1.0 inch DBH, was tallied on 0.01-acre circular plots using the same center points. These plots provided a general inventory of stem counts of reproduction over time, but they did not indicate how residual overstory trees affected the growth and distribution of reproduction within the stand.

In 2001, data were collected on randomly selected northern red oaks in the residual overstory and on the reproduction growing adjacent to or under their crowns. Measurements on the overstory trees included DBH, total height, and crown radius along the 0°, 90°, 180°, and 270° azimuths. Reproduction was tallied in four transects that radiated from the bole of the residual overstory tree oriented along the same four azimuths. The transect length was equal to the crown radius plus 15 feet along each azimuth, and the transect width was defined as the area within 5 feet of the centerline, for a total width of 10 feet (figure 1). Measurements on the reproduction included species, DBH, total height, crown class, and distance to the residual overstory tree bole for each stem found within a transect. Crown class of the reproduction was based on the status of each stem relative to neighboring stems of the same age, without regard for the residual overstory trees. Crown classes were defined by Smith (1986). The residual overstory tree crown radius minus the distance between a stem and the residual overstory tree bole defined the relative position of each stem tallied. Note

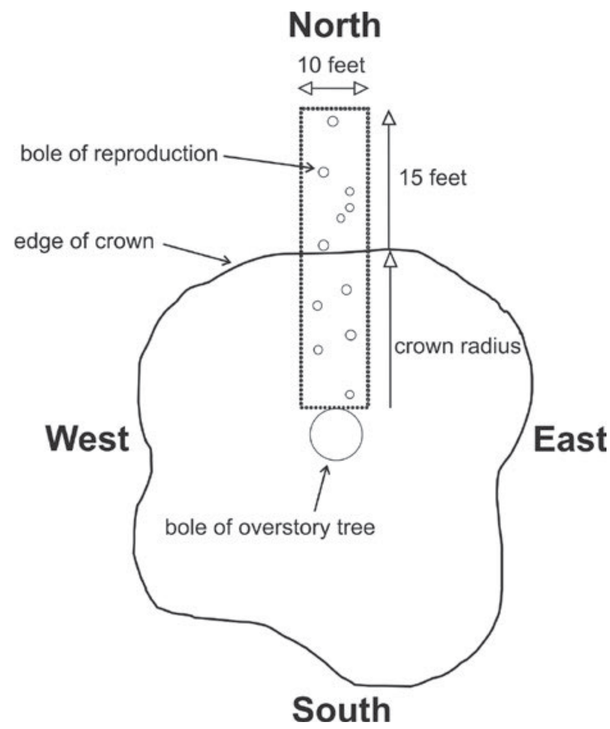


**Figure 1**—Schematic of transects used to collect reproduction data under and adjacent to residual overstory trees.

that trees with relative position <0 were located under the residual overstory tree crown, while trees with relative position >0 were located adjacent to or beyond the edge of the residual overstory tree crown. Relative position was used as a predictor in graphical and regression analyses of DBH and total height of reproduction.

The data were analyzed to determine if DBH, total height, basal area per acre, and species composition of the reproduction were related to proximity to the residual overstory trees. To conduct the analysis, reproduction was classified by two location groups and three species groups. Stems located within the overstory tree crown radius were classified as under, while stems located beyond the overstory tree crown radius were classified as adjacent. In addition, species groups were defined by shade tolerance class as defined by Trimble (1975). Intolerant stems included yellow-poplar, black cherry, and fire cherry (*Prunus pensylvanica*); mid-tolerant stems included the oaks (*Quercus* spp.), hickories (*Carya* spp.), white ash (*Fraxinus americana*), cucumbertree (*Magnolia acuminata*), and sweet birch (*Betula lenta*); tolerant stems included American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), and basswood (*Tilia americana*).

## *Statistical Analyses*

Regression analyses using the GLM procedure (SAS 2000) were used to relate DBH and total height of codominant reproduction to the position of each tree relative to the residual overstory tree crown. The assumption of common slope among the four stands was tested using analysis of covariance, which related DBH and height to stand, position, and their interaction. Violation of normality and homogeneity of variance assumptions required the use of log transformed values.

The basal area per acre of reproduction tallied within a transect by tolerance class (intolerant, mid-tolerant, and tolerant) and location (under versus adjacent) relative to a residual overstory tree was compared using a multiple factor, repeated measures analysis of variance modeled in the MIXED procedure (SAS 2000). Class variables included stand, cardinal direction, location, and tolerance class, where the latter three variables were repeated measures on a given subject residual overstory tree. Preliminary analyses of the covariance matrix revealed that the compound symmetry assumption was not feasible, so analyses were performed assuming a heterogeneous autoregressive structure. Log transformed values were also used in this analysis to account for violation of normality and homogeneity of variance assumptions.

# Results

Pre-harvest basal area averaged 138 ft$^2$/acre including poletimber and sawtimber, with an additional 5 to 10 ft$^2$/acre in saplings (table 1). The initial overstory included over 80 sawtimber-sized trees/acre with an average DBH of 15.8 inches. In general, yellow-poplar and northern red oak occupied most of the initial overstory, although black cherry, white oak (*Quercus alba*), sugar maple, and American beech also occupied significant proportions of the overstory in individual stands (table 2). Sugar maple and American beech were the most prevalent species in the pool of advanced reproduction before harvest (table 3).

Basal area in the residual stands averaged 23 ft$^2$/acre, which included 14 sawtimber-sized trees/acre with an average DBH of 17.1 inches (table 1). The composition of residual overstory trees averaged 50 percent yellow-poplar, 30 percent northern red oak, and 20 percent a mixture of other commercial species.

**Table 1—**Summary of stand characteristics before and after harvests in four central Appalachian hardwood stands.

| Stand | Number of trees 6 to 10 in.[a] | Number of trees ≥12 in. | Basal area 6 to 10 in. | Basal area ≥12 in. | Volume[b] ≥ 12 in. | Average DBH ≥12 in. |
|---|---|---|---|---|---|---|
| | ----- no./acre ----- | | ----- ft$^2$/acre ----- | | - Mbf/acre - | ---- in. ---- |
| **Riffle Creek** | | | | | | |
| Initial | 120.2 | 68.6 | 41.3 | 87.7 | 1 2,932 | 15.3 |
| Cut[c] 1979 | 118.9 | 57.4 | 40.6 | 70.9 | 10,305 | 15.0 |
| Residual | 1.3 | 11.2 | 0.7 | 16.8 | 2,627 | 16.6 |
| **Fish Trough** | | | | | | |
| Initial | 48.9 | 72.2 | 16.5 | 112.7 | 20,630 | 16.9 |
| Cut 1980 | 48.7 | 58.1 | 16.4 | 88.0 | 15,697 | 16.7 |
| Residual | 0.2 | 14.1 | 0.1 | 24.7 | 4,933 | 17.9 |
| **Shavers Fork** | | | | | | |
| Initial | 110.6 | 63.4 | 34.1 | 81.9 | 14,221 | 15.4 |
| Cut 1981 | 110.2 | 50.7 | 33.9 | 61.8 | 10,363 | 15.0 |
| Residual | 0.4 | 12.7 | 0.2 | 20.1 | 3,858 | 17.0 |
| **Red House** | | | | | | |
| Initial | 65.5 | 120.4 | 21.9 | 156.9 | 27,561 | 15.5 |
| Cut 1984 | 65.3 | 101.8 | 21.8 | 127.8 | 22,014 | 15.2 |
| Residual | 0.2 | 18.6 | 0.1 | 29.1 | 5,547 | 16.9 |
| **All** | | | | | | |
| Initial | 86.3 | 81.2 | 28.5 | 109.8 | 18,836 | 15.8 |
| Cut | 85.8 | 67.0 | 28.2 | 87.1 | 14,595 | 15.5 |
| Residual | 0.5 | 14.2 | 0.3 | 22.7 | 4,241 | 17.1 |

[a] DBH.
[b] International ¼-inch rule.
[c] All trees ≥1.0 inch DBH were felled unless selected and marked as a residual tree.

**Table 2—**Species composition before commercial harvests in four central Appalachian hardwood stands.

| Commercial species | Riffle Creek | Fish Trough | Shavers Fork | Red House | All |
|---|---|---|---|---|---|
| | ---------- % basal area/acre ---------- | | | | |
| Sugar maple | 2.4 | 6.9 | 4.0 | 2.0 | 3.8 |
| American beech | 1.9 | 14.6 | 9.3 | 0.5 | 6.6 |
| Red maple | 10.0 | 0.6 | 2.2 | 2.4 | 3.8 |
| White ash | < 0.1 | 1.5 | 4.9 | 2.5 | 2.2 |
| White oak | 20.0 | 0.0 | 1.6 | 0.0 | 5.4 |
| N. red oak | 14.7 | 5.2 | 14.8 | 15.7 | 12.6 |
| Yellow-poplar | 13.4 | 38.4 | 46.7 | 46.7 | 36.3 |
| Black cherry | < 0.1 | 3.7 | 2.7 | 27.9 | 8.6 |
| Others | 37.5[a] | 29.1[b] | 13.8 | 2.3 | 20.7[c] |
| **Totals** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** |

[a] 22% chestnut oak.
[b] 18% American basswood.
[c] Includes 17 species.

**Table 3—**Advanced reproduction ≥12 inches tall and <1.0-inch DBH present before harvests in four central Appalachian hardwood stands.

| Commercial species | Riffle Creek | Fish Trough | Shavers Fork | Red House | All |
|---|---|---|---|---|---|
| | ---------- no. of stems/acre ---------- | | | | |
| Sugar maple | 745 | 833 | 380 | 558 | 629 |
| American beech | 1575 | 450 | 1200 | 209 | 859 |
| Red maple | 340 | 0 | 0 | 47 | 97 |
| White ash | 43 | 200 | 520 | 23 | 197 |
| White oak | 128 | 0 | 20 | 0 | 37 |
| N. red oak | 255 | 33 | 40 | 140 | 117 |
| Yellow-poplar | 0 | 33 | 20 | 256 | 77 |
| Black cherry | 128 | 33 | 0 | 721 | 221 |
| Others | 169 | 18 | 140 | 279 | 150 |
| **Totals** | **3,383** | **1,600** | **2,320** | **2,233** | **2,384** |

Data were collected on woody reproduction located under and adjacent to 29 residual northern red oaks in the four study areas (table 4). Growth of the residual overstory trees in the 17- to 22-year period after deferment cutting averaged 8 inches DBH, 10 feet in total height, and 5 feet in crown radius (table 4). Based on crown radius growth the average area covered by each residual overstory tree crown increased from 660 $ft^2$ to 1170 $ft^2$, an increase of almost 80 percent during the study period.

**Table 4—**Mean DBH, total height, and crown radius of residual northern red oaks in two-aged central Appalachian hardwood stands.

| Stand name | No. of trees observed | Year | DBH | Total height | Crown radius |
|---|---|---|---|---|---|
| | | | ---- in. --- | ---------- ft ---------- | |
| Riffle Creek | 6 | 1979 | 14.3 | 89.8 | 13.3 |
| | | 2001 | 22.0 | 96.0 | 18.1 |
| Fish Trough | 7 | 1980 | 16.7 | 98.7 | 15.1 |
| | | 2001 | 25.9 | 110.9 | 20.9 |
| Shavers Fork | 8 | 1981 | 15.7 | 91.1 | 14.8 |
| | | 2001 | 25.4 | 99.6 | 21.6 |
| Red House | 8 | 1984 | 18.1 | 101.4 | 14.5 |
| | | 2001 | 24.4 | 112.9 | 16.7 |
| All | 29 | Variable | 16.3 | 95.5 | 14.5 |
| | | 2001 | 24.5 | 105.3 | 19.4 |

## *Effect of Overstory Trees on DBH and Height of Reproduction*

DBH and total height of codominant reproduction were positively related to the position of individual trees relative to the crowns of residual overstory trees (p <0.01). In general, DBH and total height increased as distance from residual overstory trees increased (figures 2 and 3). Regressions analyses also indicated that DBH and total height differed by stand (p <0.01), probably reflecting subtle effects of site quality, tree age, and species composition. Mean DBH was 3.5 inches for trees located under residual overstory trees compared to 3.9 inches (p = 0.04) for trees located adjacent to residual overstory tree crowns (table 5). Similarly, mean total height for trees located under or adjacent to overstory trees was 41.8 feet and 44.8 feet (p <0.01), respectively. The analyses revealed no interaction between stand and position, indicating that slope coefficients were not significantly different. This finding supports the general conclusion that DBH and height of codominant reproduction was strongly related to position of codominant reproduction relative to residual overstory trees, regardless of study site.

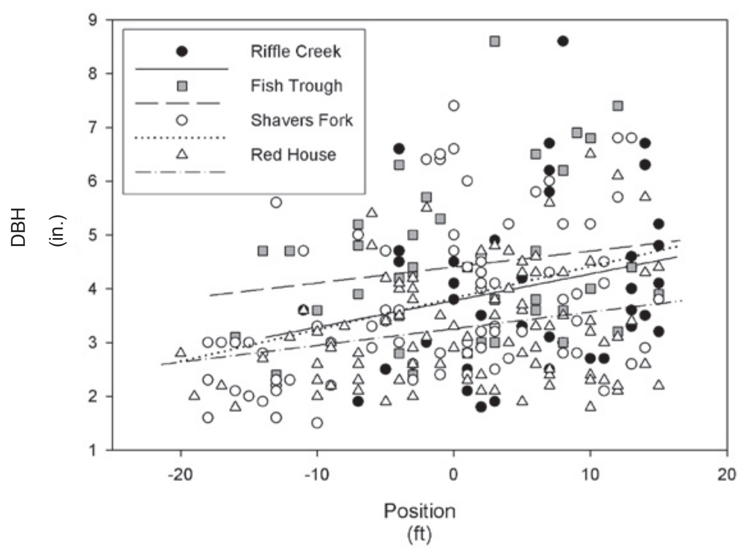


**Figure 2**—DBH of codominant reproduction by position of stem relative to edge of overstory tree crown.

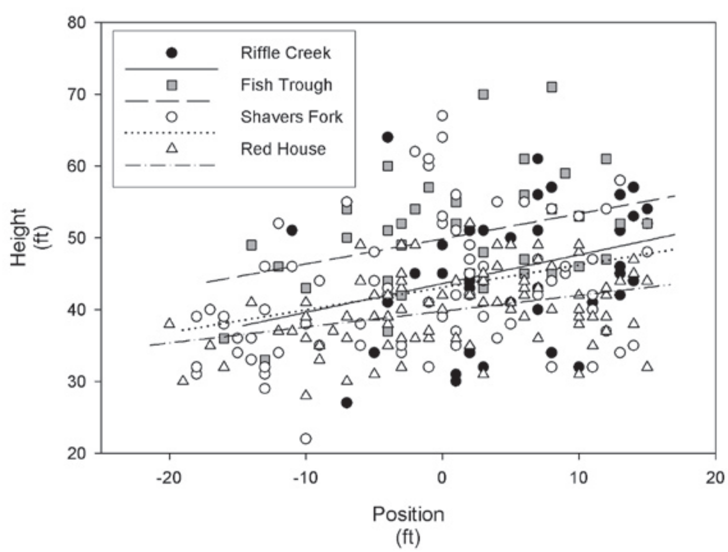


**Figure 3**—Total height of codominant reproduction by position of stem relative to edge of overstory tree crown.

**Table 5—**Mean DBH and total height of 17- to 22-year-old codominant reproduction by location relative to residual overstory trees.

| | DBH | | | Total height | | |
|---|---|---|---|---|---|---|
| | Location | | | Location | | |
| Stand | Under | Adjacent | p-value | Under | Adjacent | p-value |
| | ------------- in. (n)[a] ------------- | | | ----------- ft --------- | | |
| Riffle Creek | 3.92 (10) | 4.10 (31) | 0.76 | 45.0 | 46.1 | 0.74 |
| Fish Trough | 4.35 (20) | 4.49 (24) | 0.74 | 48.0 | 51.9 | 0.11 |
| Shavers Fork | 3.54 (43) | 3.98 (42) | 0.16 | 41.7 | 43.8 | 0.27 |
| Red House | 3.10 (42) | 3.44 (52) | 0.11 | 38.1 | 41.5 | <0.01 |
| All | 3.55 (115) | 3.90 (149) | 0.04 | 41.8 | 44.8 | <0.01 |

[a] Number of trees in sample.

## *Effect of Overstory Trees on Species Composition of Reproduction*

A recent survey of the permanent sample points located in each stand indicated that yellow-poplar, black cherry, red maple, and sweet birch accounted for most of the codominant stems in the reproduction (table 6). Other valuable species such as sugar maple and northern red oak also were present in relatively small proportions.

Based on data collected in transects in 2001, the residual overstory trees significantly influenced the distribution of species occupied by codominant reproduction (table 7). Both location ($p < 0.01$) and tolerance class ($p = 0.03$) were significant class variables, while stand and cardinal direction were not. Interaction between location and tolerance class was not evident ($p = 0.69$). Basal area of codominant reproduction adjacent to residual trees averaged 49.5 $ft^2$/acre compared to 31.7 $ft^2$/acre under residual trees ($p < 0.01$). It was clear that basal area of codominant reproduction of intolerant and mid-tolerant species was greatest in the space adjacent to residual trees, where competition for sunlight is reduced (table 7). Note that basal area of mid-tolerant species, which includes the oaks, was 18.2 $ft^2$/acre adjacent to residual trees compared to only 10.0 $ft^2$/acre under residual trees ($p < 0.01$), a difference of over 80 percent.

When all crown classes of reproduction were considered in the analysis, basal area averaged 72.5 $ft^2$/acre and 55.5 $ft^2$/acre for trees adjacent to or

**Table 6—**Composition of 17- to 22-year-old reproduction in two-aged central Appalachian hardwood stands.

| Commercial species | Riffle Creek | Fish Trough | Shavers Fork | Red House | All |
|---|---|---|---|---|---|
| | ----------------------- no. of stems/acre ----------------------- | | | | |
| Sugar maple | 128[a] (36)[b] | 300 (9) | 75 (3) | 16 (0) | 130 (12) |
| American beech | 315 (92) | 70 (0) | 170 (0) | 16 (0) | 143 (23) |
| Red maple | 187 (100) | 7 (3) | 55 (10) | 56 (5) | 76 (30) |
| White ash | 6 (0) | 25 (2) | 34 (0) | 12 (0) | 19 (1) |
| White oak | 34 (6) | 0 (0) | 170 (0) | 0 (0) | 51 (2) |
| N. red oak | 181 (79) | 17 (2) | 35 (8) | 30 (0) | 66 (22) |
| Yellow-poplar | 87 (45) | 190 (78) | 318 (112) | 656 (198) | 313 (108) |
| Black cherry | 57 (36) | 24 (8) | 9 (3) | 228 (86) | 80 (33) |
| Others | 448 (225) | 311 (88) | 21 (20) | 467 (139) | 312 (118) |
| **Totals** | **1443 (619)** | **944 (190)** | **887 (156)** | **1481 (428)** | **1189 (349)** |

[a] All stems ≥ 1.0 inch DBH.
[b] Dominant and codominant stems.

**Table 7**—Mean basal area per acre of 17- to 22-year-old reproduction by tolerance class and by location relative to residual overstory trees.

| Location | Transect sample size | Tolerance class | | | Total |
|---|---|---|---|---|---|
| | | Intolerant | Mid-tolerant | Tolerant | |
| | n | ft²/acre | | | |
| | | All trees | | | |
| Adjacent[a] | 91 | 24.9 | 24.7 | 22.9 | 72.5 |
| Under | 91 | 19.3 | 17.2 | 19.0 | 55.5 |
| | | Codominant trees | | | |
| Adjacent | 91 | 19.9 | 18.2 | 11.4 | 49.5 |
| Under | 91 | 15.1 | 10.0 | 6.6 | 31.7 |

[a] Reproduction was located under residual overstory tree crowns or adjacent to residual trees where there was no residual overstory competition.

under residual trees, respectively, but the distribution of species was not affected by location relative to the residual overstory trees (table 7).

# Discussion

The analysis focused on the composition and development of codominant reproduction, while subordinate stems received little attention. At the 20-year stage of development, when crown classes are evident, codominant stems are those most likely to remain competitive for an extended time. For intolerant and mid-tolerant species, in particular, subordinate stems have little chance of exhibiting sufficient height growth to survive or maintain their position in the canopy of an aggrading stand (Trimble 1973). Intolerant species also are more likely to lose competitiveness once they become subordinate to neighboring trees of the same age or receive overhead competition from older, taller trees.

The observed influence of overstory trees on reproduction will increase as the crowns of the overstory trees expand. When transect data were recently collected, the residual overstory trees were approximately 100 years old, and the reproduction ranged from 17 to 22 years old. Overstory trees were more than 100 feet tall, while codominant reproduction was less than 50 feet tall. Height growth of the residual overstory trees was relatively slow, about 0.5 ft/yr (table 4), compared to 4.5 ft/yr (table 5) for the reproduction. At these rates of growth, the reproduction needs an additional 30 to 40 years to become competitive with overstory trees. Similarly, the crowns of residual overstory trees are likely to expand and continue to influence the development of the reproduction for many years. In this study, retaining 15 trees per acre with an average DBH of 16 inches resulted in a 22 percent canopy cover immediately after the harvest. After 20 years, average DBH had increased to 24 inches, and canopy cover had increased to 39 percent. In a few more years, nearly half of the stand area will be located under the crowns of the residual overstory trees. It is apparent from these observations that successful reproduction of valuable intolerant and mid-tolerant species will be limited to less than half the stand area in years to come.

Northern red oak has a relatively large crown area compared to other species of the same DBH (Lamson 1987). The results presented here represent a worst-case scenario in terms of how the residual overstory trees can exhibit a negative impact on reproduction, particularly shade-intolerant species. Species with smaller crowns or less aggressive crown expansion would tend to occupy less of the stand area compared to northern red oak.

Reproduction in the new age class would benefit from an intermediate cultural practice such as cleaning or crop tree release (Miller 2000). These precommercial treatments free selected codominant stems from crown competition, thus accelerating their growth and increasing their future competitiveness. In two-age stands, however, opportunities to successfully release intolerant and mid-tolerant species may be limited to areas located between the residual overstory trees.

This study did not compare reproduction in two-age stands to that observed in even-age stands, but there is evidence that the residual overstory trees in two-age stands reduced the overall growth of codominant reproduction, regardless of its location. Data collected from 17-year-old even-aged stands located a few miles from the experimental two-age stands indicated that average DBH exceeded 6 inches and average total height exceeded 50 feet for codominant reproduction on site index 70 (Miller 2000). By comparison, DBH and total height of codominant trees located adjacent to residual overstory trees in the two-age stands averaged only 4 inches and 45 feet, respectively (table 5). Codominant reproduction located under the residual overstory trees was even smaller.

There are several alternative strategies for managing two-age stands to reduce the impact of residual overstory trees on reproduction:

- Leave fewer trees per acre in the initial harvest operation.
- Leave species with relatively smaller crowns and less aggressive crown expansion.
- Leave clumps of residual trees to increase open space and reduce the effect of residual tree crown expansion.
- Start with 15 residual trees per acre, but reduce the number of residual trees by chemical or mechanical means once the new age class is established.

Finally, it is important to prepare for the regeneration of desired species many years before conducting harvests in hardwood stands (Miller and Kochenderfer 1998). An assessment of the regeneration potential should be conducted before a planned harvest to determine if preparatory silvicultural treatments are needed. The negative impacts of interfering plants and high deer populations must be controlled to allow desirable advanced reproduction to develop many years before a planned harvest. Once competitive advanced reproduction is in place, removing most or all of the overstory will provide the light and seedbed conditions for a new age class of desirable trees to develop.

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