Research on Diameter-Limit Cutting in Central Appalachian Forests

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Introduction

In their abundance and quality the mature, second-growth forests of the Central Appalachian region are a valuable timber resource for landowners, forest industries and the general public. As these forests are harvested, maintaining their productive capacity and conserving tree species diversity are important considerations for long-term sustainability according to the Montreal Process Criterion and Indicators (http://www.mpci.org/criteria_e.html). Current stands typically contain more than 20 tree species representing a range of silvical characteristics (Miller and Kochenderfer 1998; Brashears et al. 2004). As a result, establishing new cohorts with species representative of the forest that preceded them requires planned silvicultural treatments before harvest. Long-term silvicultural research has produced guidelines for sustainable management of these forests (e.g., Roach and Gingrich 1968; Smith and Eye 1986; Nyland 1987; Marquis et al. 1992) that are used widely on publicly owned lands in the region (USDA For. Serv. 1986).[1] However, these guidelines are rarely followed on most of the private land in this region or elsewhere in the Northeast (Fajvan et al. 1998; Pell 1998; unpublished data).

Because private nonindustrial forests account for nearly 80 percent of forest ownership in the Central Appalachians (Smith 1994), harvesting practices on these ownerships affect landscape attributes such as wildlife habitat, scenic quality, recreational opportunity, and economic value. Forest industry is the foundation to sustaining these values by making forest management economically feasible for landowners. Yet in 1995, assessments of timber harvesting practices conducted in three states suggested that these practices threaten the diverse supply of raw materials essential to support such an industry (Fajvan et al. 1998; Pell 1998; unpublished data). Forest sustainability also can be affected because the most vigorous overstory trees are removed during a diameter-limit harvest. Although trees in the intermediate crown class and understory trees receive more growing space, many of these low-vigor stems will die or grow slowly (Marquis and Ernst 1991). There also is a reduction in seed sources of high-value species that are selectively removed (high-graded) down to the smallest merchantable diameters. For example, in West Virginia, 36 percent of the harvests surveyed in 1995 showed reductions of more than 80 percent in basal areas of northern red (*Quercus rubra*) and white oaks (*Quercus alba*), yellow-poplar (*Liriodendron tulipifera*), ash (*Fraxinus Americana/Fraxinus pennsylvanica*), and black cherry (*Prunus serotina*) (Fajvan et al. 1998). Such reductions have important implications for future timber supply, stand productivity, and economic returns available to landowners. Biodiversity and ecosystem resiliency also are affected as species are selectively removed during repeated partial harvesting (Schuler 2004).

Diameter-limit harvests (or any partial canopy removal harvest) are classified as minor disturbances (Oliver and Larson 1996) because some trees that predate the disturbance survive. These trees may increase in growth if they are healthy, have sufficient live crowns and are undamaged from logging. Alternatively, if the residual trees previously were in subordinate crown positions, their growth increase may be marginal, stem quality may be lost due to epicormic sprouting, or mortality can occur (Roach and Gingrich 1968). If sufficient growing space has been created by the harvest, regeneration may develop from new seedlings, advance regeneration, and sprouting.

In this paper I review past and current research on the effects of diameter-limit harvesting on the stand structure, productivity, regeneration, and overall sustainability of even-aged hardwood forests. Results of past monitoring studies in West Virginia, Pennsylvania, and New York are summarized, and new data are presented from long-term studies on the West Virginia University Forest.

[1]An evaluation of the Pennsylvania Department of Conservation and Natural Resources Bureau of Forestry under the SCS ConservationProgram (2005). Unpublished report available from the Pennsylvania Bureau of Forestry, Harrisburg.

Review of Research on Diameter-Limit Harvesting

1995 Timber Harvest Assessment

In 1995, scientists and managers in New York, Pennsylvania, and West Virginia examined postharvest stand attributes in an attempt to describe future forest sustainability. Ninety-nine harvests were sampled in West Virginia, and 99 and 62 harvests were sampled in Pennsylvania and New York, respectively. Following examination of pre- and postharvest stand structures, analyses focused on describing harvesting practices and resulting effects on sustainability. The studies confirmed that diameter-limit harvesting was practiced on about half of the harvests surveyed in New York (unpublished data) and Pennsylvania (Pell 1998), and on 80 percent of the harvests in West Virginia (Fajvan et al. 1998). The remaining harvests consisted of intermediate treatments such as thinnings, or regeneration harvests such as shelterwood seed cuts and clearcuts.

Regardless of harvesting practice, residual stand conditions in all three states were analyzed with respect to total stocking, stocking of commercially desirable species, and stem quality, to determine whether it still was feasible to manage for sawtimber in the current rotation. In New York and West Virginia, only 20-27 percent of harvests had desirable residual conditions. In Pennsylvania, about half of the harvests produced desirable conditions. Because diameter-limit harvesting does not take future stand condition into account, the typically irregular spatial distribution of residual trees can affect new cohort development and restrict future management options. In 68 percent of the harvests surveyed in New York, cutting increased stocking variability by at least 1.5 times, i.e., the residual stand was more "patchy" than preharvest conditions. The distribution of regeneration also is irregular because the regeneration is concentrated in large gaps.

Effects of Diameter-Limit Cutting on Regeneration Composition and Density

In 1998 we revisited 86 of the sites from West Virginia's 1995 harvest assessment to measure regeneration characteristics as part of a collaborative effort by the West Virginia Sustainable Forestry Initiative Committee, West Virginia University, and the West Virginia Division of Forestry. Our objective was to create a model that uses stand-structure variables to predict regeneration density after harvesting. Forest ownerships ranged in size from 20 to 5,000 acres but sampling occurred in harvested stands ≤ 150 acres. Fifteen, circular plots (1/20 acre) were established randomly in each stand to measure trees ≥ 1.0 inch at 4.5 feet above the ground (d.b.h.) and record percent cover of all other woody and herbaceous vegetation and exposed rocks. Three milacre plots were nested within each larger plot to measure new seedlings and sprouts < 1.0 inch d.b.h. and record the number of browsed seedlings.

Table 1.—Seedling densities from 39 partial harvests (residual stocking < 50 percent) in West Virginia.

Species	Mean seedlings/ acre	Percent seedlings > 3 ft tall
American beech	236	30
White oak	270	4
Hickory	341	7
Black cherry	408	23
Ash	410	13
Chestnut oak	443	5
Birch	491	14
Red/Black oaks	682	14
Sugar maple	686	14
Yellow-poplar	953	18
Red maple	2736	5

Residual basal area averaged 58 ft^2/acre statewide (range: 0 to 152 ft^2/acre) and was dominated by red maple (*Acer rubrum*), yellow-poplar, and chestnut oak (*Quercus prinus*). Residual trees per acre were primarily red maple (17 percent), sugar maple (*Acer saccharum*) (16 percent), beech (*Fagus grandifolia*) (8 percent), yellow-poplar (6 percent), and hickory (*Carya* sp.) and black gum (*Nyssa sylvatica*) (5 percent each). Except for American beech and chestnut oak, over 90 percent of regeneration was classified as new seedlings. Forty percent of the harvests were considered "adequately stocked" under the criteria of 5,000 to 10,000 seedlings per acre and 85 percent of milacre plots stocked with one or more stems ≥ 1 foot tall (Trimble 1973). Red maple was the most abundant species statewide, followed by yellow- poplar, which had the most seedlings > 3 feet tall (Table 1).

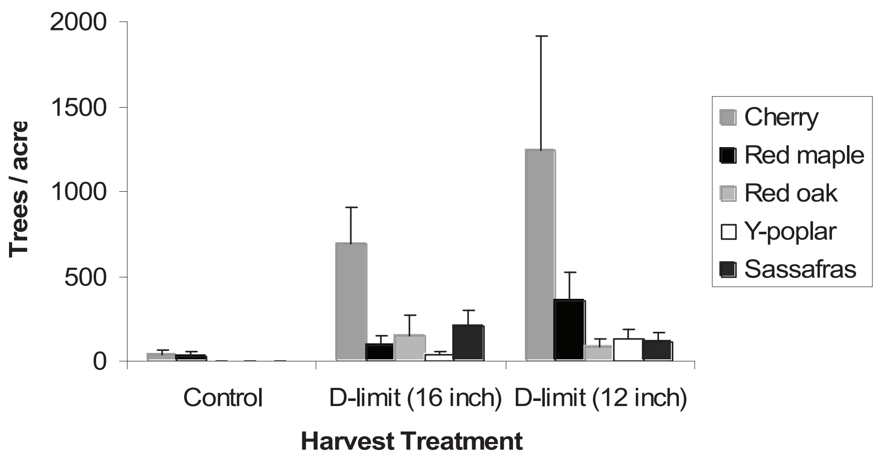

Figure 1.—Mean regeneration density (trees per acre) and species composition of seedlings > 20 inches tall 5 years after diameter-limit harvesting (uncut control, 16-inch diameter limit, 12-inch diameter limit) on the West Virginia University Forest.

Only 39 stands were included in the regression analyses for modeling regeneration density. These were the stands that had < 50 percent stocking after harvest and were classified previously (Fajvan et al. 1998) as having sufficient growing space for regeneration establishment. Data on stand structure from the 1/20-acre plots were averaged for each stand. Independent variables in the regression model included preharvest basal area, preharvest trees per acre, residual basal area in each of three height classes (1 to 20, 20 to 50, and > 50 feet), total residual basal area, residual trees per acre, and percent basal area removed. Percent browsed seedlings and percent cover of other woody and herbaceous vegetation and exposed rocks were averaged from the milacre plots for each stand and also included as variables. The dependent variable was the number of seedlings per acre ≥ 1 foot tall.

Multiple regression was used to determine which independent variables explained the greatest amount of variation in the data and should be included in the final model. An adjusted coefficient of determination was used to evaluate each model. The final model had an adjusted R^2 of 0.71 and included four variables that were most highly correlated with regeneration density:

$$Y = 7557.40 - 7.74*B1 - 44.25*B2 - 118.99*B3 + 67.10*B4$$

where:

Y = Seedlings/acre ≥ 1 foot tall (commercial species)
B1 = Residual trees/acre
B2 = Percent cover of herbs
B3 = Percent cover grass
B4 = Residual basal area/acre for trees 20 to 50 feet tall

There was a negative relationship of seedling density with total residual trees per acre and percent cover of herbs and grass. However, number of seedlings was positively correlated with residual basal area of trees 20 to 50 feet tall, which included most of the residual overstory. Most trees taller than 50 feet probably were removed in the harvests. The "high shade" produced by this canopy may have had a positive effect on shade-tolerant red maple, which dominated the regeneration. Also, at the time of this study, the regeneration had developed only for 4 to 5 years postharvest so perhaps insufficient time had elapsed for shading to have a negative effect on regeneration density.

Effects of Residual Trees on Regeneration Composition and Size

In 1993, four stands on the West Virginia University Forest in north-central West Virginia, were divided into three, 10-acre treatment blocks to receive a 12-inch diameter-limit harvest, a 16-inch diameter-limit harvest, or no harvest. The trees were about 60 years old. Stands were located on northern aspects, had average basal areas of 150 ft^2/acre, and were composed of yellow-poplar (50 percent of basal area), northern red oak (30 percent) and lesser amounts of red maple, black cherry and white oaks. Residual basal areas in the 12-inch harvest ranged from 10-30 ft2/acre and 30 to 60 ft^2/acre in the 16-inch harvest.

Regeneration composition was sampled prior to harvesting and annually for 5 years (Fig. 1), and again

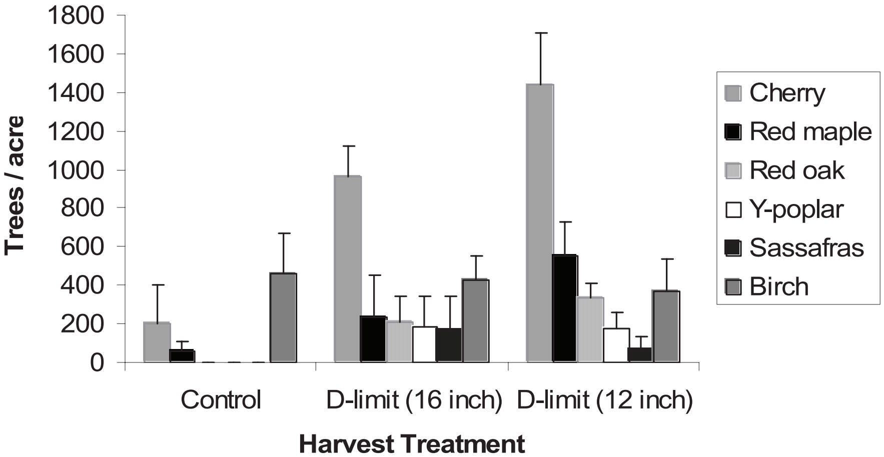

Figure 2.—Mean regeneration density (trees per acre) and species composition of saplings 1 to 5 inches d.b.h., 9 years after diameter-limit harvesting (uncut control, 16-inch diameter limit, 12-inch diameter limit) on the West Virginia University Forest.

Table 2.—Mean d.b.h., total height, live crown ratio, and crown projection areas of 130 residual trees measured 9 years after a 16-inch diameter limit harvest on the West Virginia University Forest (standard errors are in parenthesis).

Species	Number of trees	D.b.h.	Total height	Live crown ratio	Crown projection area
		inches	*feet*		*ft²*
Chestnut oak	10	13.6 (0.4)	86.2 (2.4)	47.4 (2.1)	358.2 (39.3)
Red maple	40	10.2 (0.3)	61.0 (1.9)	57.7 (1.2)	341.1 (21.5)
Red/black oak	30	14.4 (0.4)	80.9 (2.2)	56.0 (1.5)	393.1 (27.4)
White oak	10	11.2 (0.5)	78.6 (2.8)	45.2 (2.0)	275.5 (35.4)
Yellow-poplar	40	14.5 (0.3)	82.7 (1.9)	52.0 (1.4)	252.3 (15.8)

at 9 years (Fig. 2). After 5 years, the 12-inch harvests had more regeneration > 3 feet tall than the 16-inch diameter limit (2,307 ± 612 vs. 1,273 ± 387 trees per acre, respectively). The uncut stands had less regeneration (293 ± 166) than the harvested sites. The 12-inch harvests had the lowest residual basal areas partly because 10 percent of the residual trees were destroyed during logging (Fajvan et al. 2002). These stands resembled clearcuts and had more sunlight and growing space to support higher regeneration densities than the 16-inch diameter-limit harvests. Regardless of treatment and time since harvest, black cherry was the most abundant species in the regeneration even though overstory black cherry represented only about 10 percent of the basal area before treatment. Black cherry also was the most abundant species of advance regeneration (see Fig. 1 Control) because it is not preferred as browse by white-tailed deer.

In 2003 we examined the effects of the residual trees in the 16-inch diameter-limit harvests on regeneration size and species composition to determine whether shading from the residual tree crowns affected the importance of shade-tolerant versus shade-intolerant species under tree crowns compared to the species composition of saplings in the gaps between crowns. A sample of 130 residual trees ranging in size from 7 to 17 inches d.b.h., were selected randomly from the four, 16-inch diameter-limit harvests proportional to their species' and size (diameter) representation in the stand (Table 2). Yellow-poplar and red maple were the most abundant species with average heights ranging from 61 to 86 feet. These 130 trees were used as plot centers, and saplings (1 to 5 inches d.b.h.) were sampled on 5-foot-wide transects arranged along 0, 90, 180 and 270 degree azimuths. Transects were variable in length because they extended 5 feet beyond the crown edge in their respective direction.

Because of the irregular spacing among residual trees, some crowns of the plot center trees overlapped other residual trees in the vicinity. Thus, saplings could be located under two or three overlapping crowns. Sapling total height, diameter, crown class (relative to associated saplings), and their distance from the plot center tree were measured. Sapling data also were categorized according to their location relative to residual tree crowns: 1) under the center tree 2), outside the crown of the center tree 3), under the center tree and an overlapping crown(s) and 4) outside the crown of center tree but under the crown(s) of adjacent trees.

Preliminary results indicated that of the 2,239 saplings sampled, black cherry was the most abundant species (importance value = 0.37) followed by red maple (importance value = 0.15). Red/black oaks, black birch and yellow-poplar each had importance values around 0.10. Twelve percent of the saplings were in the dominant/codominant crown classes with black cherry accounting for 45 percent of these followed by red maple and black birch about 13 percent each. The mean height of red maple (17.3 feet ± 0.5 foot) was greater than that of black birch (16.8 feet ± 0.5 foot) and black cherry (16.3 feet ± 0.3 foot). The average height of red/black oaks (8.2 feet ± 0.5foot) was about 50 percent less than that of these other species.

Saplings growing outside the crown of the center tree were taller (16.5 feet ± 0.3 foot) than those growing under its crown (15.3 feet ± 0.2 foot) or under its crown and another crown (14.6 feet ± 0.6 foot) or under the crowns of one or more other residual trees along the transect (14.5 feet ± 0.7 foot). Basal area and mean total heights of dominant/codominant saplings also were greater outside the center tree crown (57.3 ± 3.9 ft^2, 26.4 feet ± 0.6 foot) than under its crown (28.6 ± 2.4 ft^2, 24.7 feet ± 0.4 foot), or under its crown and another crown (12.7 ± 4.9 ft^2, 20.4 feet ± 1.3 foot), or under the crowns of other trees along the transect (53.1 ± 12.1 ft^2, 20.9 feet ± 1.02 foot).

Discussion

The studies discussed here expand our knowledge about the effects of partial cutting on stand structure, but this information does not alter our basic understanding of stand dynamics and minor disturbances. For example, Roach and Gingrich (1968) described residual stands resulting from past (partial) "overcutting" as having an "irregular crown canopy" with residual mature trees that generally "will deteriorate in quality" and with "desirable reproduction that will not develop properly." They observed that desirable (shade-tolerant) regeneration probably is present if stand stocking is below the C-level, but that it would eventually be overtopped by a less desirable "understory of tolerant brush." They recommended that the overstory be removed as soon as possible before residual tree quality deteriorated further and to favor growth of desirable (shade-intolerant) regeneration. Although timber markets have changed during the past 40 years, exploitative harvesting practices have not. The 1995 West Virginia harvest assessment and subsequent regeneration survey indicated that shade-intolerant, high-value species are favored removals in the harvests and that shade-tolerant maples and beech dominated the residual stands. Even though the tallest species of regeneration was shade-intolerant yellow-poplar 4 to 5 years after harvest, the density of red maple was nearly three times greater.

Another study on the West Virginia University Forest indicated that after clearcutting, red maple had slower height growth than yellow-poplar and black cherry but could grow as fast as red oak to eventually occupy a codominant crown position in the overstory with oak and poplar (Tift and Fajvan 1999). However, 9 years after diameter-limit cutting, our data suggest that partial overstory shade is more favorable to red maple height growth than to the growth of black cherry and yellow-poplar. Red/black oaks accounted for only 1 percent of the dominant/codominant stems and generally were overtopped by the other species. Of course factors such as intensity of deer browsing, annual seed production, site quality, and climate contribute to regeneration composition and development. For example, selective browsing by white-tailed deer rather than diameter-limit cutting was primarily responsible for the preponderance of black cherry on the West Virginia University Forest, even in the uncut stands. However, these variables were not measured in all of the studies discussed and are not reported here.

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