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# Long-term Assessment of Financial Maturity, Diameter-limit Selection in the Central Appalachians


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## Abstract

Simple diameter-limit cutting is an exploitive harvesting technique that contributes to lower stand values and has depleted high-quality sawlog resources in the central Appalachian region. Financial maturity, diameter-limit (FMDL) selection was proposed more than three decades ago as a replacement for diameter-limit cutting. FMDL incorporates financial maturity guidelines for individual trees, high-priority removal of poor-quality trees, and guidelines for residual basal area (RBA). We provide the first long-term assessment of this practice. Three levels or rate-of-return treatments (3, 4, and 6-percent) were replicated twice on 240 acres. We compared these treatments after three to four 10-year periodic harvests with respect to board foot productivity, RBA, butt-log quality, and species composition. The 3- and 6-percent treatments were the most disparate after three periodic harvests yielding 278 and 523 board feet/acre/year, respectively. The 6-percent treatment averaged 445 board feet/acre/year after the fourth periodic harvest. RBA did not differ significantly by treatment or harvest period, though postharvest basal area usually was less than the heretofore previously recommended minimum of 55 $ft^2$/acre for sawlog-size trees. Butt-log quality did not differ by the experimental design but on average was stable or improving through time for all three treatments. Composition in all three treatments was increasingly dominated by shade-tolerant species. Empirical evidence suggests that lowering the minimum RBA of sawlog-size trees to 45 $ft^2$/acre on good sites (SI 65 to 74) is required to implement the 6-percent rate of return treatment.

## Cover Photo

Fernow Experimental Forest, compartment 20B, camera point 5 in 2006 after three decades of FMDL selection using 4-percent rate-of-return guidelines

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## INTRODUCTION

Diameter-limit cutting is the dominant type of timber harvesting on the vast network of nonindustrial private forests (NIPF) in the Eastern United States (Fajvan and others 1998; Nyland 2001). Positive attributes of this method include periodic cash flow, little to no investment, and retention of standing green trees that mitigates the visual effects of harvesting and provides residual growing stock for the next cycle of stand growth. However, in practice, diameter-limit cutting ignores goals for residual stocking and seldom removes poor-quality trees. Throughout the Appalachians, 12 inch diameter at breast height (d.b.h.) or stump-diameter limits of 14 inches often are used because trees of this size generally return a profit but also contribute to lower stand values (Smith 1980; Nyland 2005).

In West Virginia, diameter-limit cutting was ranked by service foresters as one of the most severe forest management practices (McGill and others 2004). In Ohio, Pennsylvania, and West Virginia alone, 22.5 million acres of timberland recently were classified as sawtimber-size stands (http://www.fs.fed.us/ne/fia/states, 18 January 2006). It is this type of stand that is at risk or already has been subjected to exploitive and unsustainable timber harvesting (Fajvan and others 1998) that disrupts a continuous output of desired products and degrades future productivity on the site.

Empirical studies spanning up to 50 years generally have confirmed the observed negative effects of repeated diameter-limit cutting. Reduced growth through time and a reduction in residual stem quality were documented by Sokol and others (2004), Kenefic and others (2005), and Ward and others (2005). However, growth trends are not always negative and may depend on the initial stand structure and the random nature of the spatial and size distribution of residual stems following diameter-limit cutting (Schuler 2004). During the onset of trials using diameter-limit cutting, revenue generation and compounded rates of return are higher than other partial cutting practices, but residual stand values usually are lower (Miller 1993; Kenefic and others 2005). Nyland (2005) used computer simulation to evaluate the long-term effects of this cutting practice. He concluded that the only advantage with diameter-limit cutting is the high volume and value produced during the first harvest cycle of a well-stocked, uneven-aged stand.

Negative perceptions of diameter-limit cutting should be tempered by the fact that most timber harvests (including those in trials) that remove trees based on diameter alone make no minimum residual stand specifications or prescribe other treatments to the harvested stand that might counteract the associated negative effects of this cutting practice. For example, some practices that are reported as diameter-limit cuts have such low diameter limits (Erdmann and Oberg 1973; Strong and others 1995; Niese and others 1995) that they might be considered "commercial clearcuts" which remove all useable stems, usually to about 5 inches d.b.h. Even selection systems with harvesting guidelines that prioritize the elimination of cull or lower quality trees can result in diameter limit-like residual stands if the initial stand has a high proportion of large remnant culls from previous cuttings (Orr and others 1994). By contrast, modeling research in northern and southern hardwood forest types revealed that diameter-limit cutting may be sustainable for some forest management objectives (Volin and Buongiorno 1996; Buongiorno and Vasievich 2000; Buongiorno and others 2004).


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Trimble and others (1974) proposed a silvicultural alternative to diameter-limit cutting and the seldom used and more complex single-tree selection that combined periodically harvesting individual sawlog-size trees at financial maturity, an improvement cut at each harvest cycle, and guidelines for residual basal area (RBA). Trimble referred to this type of silviculture as financial maturity, diameter-limit (FMDL) selection. Referring to this type of harvesting as a variant of diameter-limit cutting may be inappropriate because the FMDL method requires the removal of not only cull but also trees of poor vigor and poor quality, some control of species composition, and guidelines for RBA. Thus, FMDL also can be considered a variant of an uneven-age selection system.

The FMDL process of determining the financial maturity of individual trees is based on site index (SI), tree size, conversion costs, lumber values, and associated species values (Mendel and Trimble 1969; Trimble and Mendel 1969; Grisez and Mendel 1972; Mendel and others 1973). Although financial maturity guidelines will change with technology and markets, it is not our intent to evaluate species-specific, financial maturity guidelines. However, if the silvicultural approach proves sustainable, periodic updates to the financial maturity guidelines should be developed for regional markets to reflect more current conditions. In reviewing practical considerations when applying FMDL, Miller and Smith (1993) concluded that most of the objectives of single-tree selection can be achieved with this approach. Here, we expand on existing research by providing the first long-term comparison of three harvest intensities using FMDL. We compare merchantable yield, residual stocking, quality of harvested logs, and species composition over time for up to three 10-year cutting cycles and four periodic harvests, and discuss management implications, potential silvicultural improvements, and future research needs.

## FINANCIAL MATURITY DIAMETER-LIMIT SELECTION

With FMDL, a stand-improvement operation is carried out and sawtimber-size trees that fall below a desired rate of return are harvested. Trees that exceed a specified rate of return are left to grow and appreciate in value, assuming a 10- to 15-year cutting cycle. Financial maturity guidelines for individual trees have been developed based on species, SI, and desired rate of return (Appendix). In addition to removing trees that are financially mature, an improvement cut is prescribed at each periodic harvest to improve residual stand quality (Appendix). Poor-quality or high-risk trees designated for removal have low or negative rates of return and occupy growing space that could be used for establishing new regeneration and/or used by trees with better rates of return. In practice, it has been recommended that the improvement cut should be estimated first and then the rate-of-return marking guideline selected to achieve the desired RBA in sawlog-size trees as follows: SI 80: 70 to 85 $ft^2$/acre, SI 70: 55 to 70 $ft^2$/acre, SI 60: 40 to 55 $ft^2$/acre (Trimble and others 1974; Miller and Smith 1993). Stands that fall below RBA guidelines might be unable to produce the expected periodic board foot volume growth, which is about 200, 300, and 400 board feet/acre/year for northern red oak site 60 (fair), 70 (good), and 80 (excellent), respectively, in central Appalachian hardwoods (Miller and Smith 1993).

Trimble and others (1974) pointed out that with any selection system, not all stands can be managed reasonably. Those with a mixture of both sawlog- and pole-size trees are best suited to the initiation of the financial maturity guidelines presented here. In appropriate stands, adjusting the rate of return (Appendix) can result in residual stands within the desired RBA range and may provide sufficient merchantable volume marked for harvest to attract buyers. Mature stands that have been repeatedly high-graded may lack sufficient growing stock with which to sustain subsequent harvests after all of the poor-quality and high-risk trees have been removed. In this case, two-age or even-age management may be more appropriate. Also, stands that are predominantly pole size cannot be managed using financial maturity guidelines. For young stands, there are other timber management options such as cleaning, basal-area thinning, crop-tree management, and waiting. Experienced foresters can recognize these situations and can provide the landowner with various options depending on their management objectives. An overview of when and how to apply the FMDL method is found in Trimble and others (1974) and Miller and Smith (1993).

**Table 1.—History of financial maturity diameter-limit cutting treatments by research compartment on the Fernow Experimental Forest in West Virginia**

| Compartment | Number of Acres | Treatment | Harvest year |
|---|---|---|---|
| | | Percent | |
| 26A | 32.1 | 6 | 1971, 1981, 1991,2004 |
| 26B | 14.2 | 6 | 1971, 1981, 1991,2004 |
| 60 | 31.0 | 4 | 1981, 1991,2004 |
| 20B | 25.3 | 4 | 1977, 1987, 1996 |
| 31 | 18.9 | 3 | 1972, 1982, 1992, 2004 |
| 61 | 118.0 | 3 | 1983, 1993, 2004 |

# MATERIALS AND METHODS

## Study Area

This study was conducted on the Fernow Experimental Forest (39°3´ N, 79°40´ W) within the Monongahela National Forest in north-central West Virginia. Elevations on the study sites range from about 2,270 to 3,160 feet above sea level. The average growing season is 145 days (May - October), and mean annual precipitation is about 56 inches and is distributed evenly throughout the year (Pan and others 1997). The ecological land type of the Fernow is referred to as the Allegheny Sideslopes of the Central Appalachian Broadleaf Forest (McNab and Avers 1994). This study encompasses six management units (research compartments) on 240 acres (Table 1). Each compartment is classified as northern red oak SI 70. This is considered as a good site for timber production and is representative of much of the central Appalachian region. Keeping SI constant among treatments was intentional to avoid confounding the results by differences in potential site productivity. The oak SI of Schnur (1937) was determined for each compartment by field sampling using the equation developed by Trimble and Weitzman (1956).

The tract of land that later became the Fernow was logged initially between 1903 and 1911 during the railroad logging era (Schuler and Fajvan 1999). During this period, some trees were left uncut because their size or form did not meet the standards of the day, or because the species was undesirable. The Federal Government purchased the land in 1915 and silviculture and watershed research on the Fernow began in 1933. When this study was initiated in 1975, some stands already had been treated using FMDL procedures (Table 1). Before 1970, some stands had received a conditioning cut to remove culls or poorly formed old-growth residuals. During the 1930s, chestnut blight, first noted in West Virginia in 1909, resulted in a reduction in standing timber of 25 percent on the Fernow (Weitzman 1949). In 1975, the research compartments in this study were predominantly even-aged and about 65 years old.

Species composition on the study sites is best described as mixed-mesophytic (Braun 1950). Common overstory species include northern red oak (*Quercus rubra* L.), chestnut oak (*Q. prinus* L.), sugar maple (*Acer saccharum* Marsh.), red maple (*A. rubrum* L.), yellow-poplar (*Liriodendron tulipifera* L.), American beech (*Fagus grandifolia* Ehrh.), cucumbertree (*Magnolia acuminata* (L.) L.), black cherry (*Prunus serotina* Ehrh.), basswood (*Tilia americana* L.), and white ash (*Fraxinus americana* L.). Understory species composition is rich and often includes stinging nettle (*Laportea canadensis* L.), violets (*Viola* spp.), and several fern species, and is dependent on site and disturbance history (Gilliam and others 1995). Soils on the study sites are predominantly of the Calvin series and developed on uplands in material weathered from sandstone, acid red shale, and slightly calcareous red shale (USDA Soil Conserv. Serv. 1967). These soils are well drained, moderately permeable, and strongly acidic. Natural fertility is moderate and the average depth to bedrock is 32 inches.

## Treatments

Three rate-of-return treatments (3, 4, and 6 percent) were evaluated in this study (Appendix). Each compartment was assigned a treatment and each treatment was replicated in two compartments (Table 1). Marking for the improvement cut (Appendix) usually occurred in tandem with marking according to the financial maturity guidelines. Rate-of-return marking guidelines remained constant in each of the assigned compartments. We did not adjust them to achieve a more desirable RBA because our intent was to determine whether different harvest intensities were sustainable through time and multiple harvests by examining their effects on RBA and productivity. Since 1971 there have been 22 harvests on a planned 10-year cutting cycle. All compartments have been harvested at least three times and four have been harvested four times, though the 1973 harvest in Compartment 61 was not documented according to study protocol and could not be included in this analysis (Table 1).

Because this is an ongoing study and harvests are staggered, we do not anticipate an equal number of harvests in each compartment at the same time. Past deviations in the 10-year cutting cycle were due to logistical constraints in scheduling timber harvests. A USDA Forest Service logging crew conducted all of the timber harvests using conventional ground-based logging equipment (i.e., trees were felled by sawyers, tree-length logs were winched to skid roads, and logs were skidded to decks with rubber-tired skidders or crawler-tractors). Other areas on the Fernow have been treated with FMDL selection for demonstration purposes but have not been replicated and are not evaluated here.

## Data Collection

At study inception, inventories of each compartment were conducted for all trees more than 5 inches d.b.h. by 2-inch class before each cutting cycle. Each tree was recorded by species and classified as merchantable, cull, or dead. Most cull material was removed in the first cutting cycle and no longer is prominent in any compartment. In 1986 and thereafter, permanent growth plots (0.5 acre) were located systematically throughout the compartments and replaced the 100-percent tally system prior to each cutting cycle so that stand structure and species composition could be determined. Sufficient numbers of plots were installed to achieve a 10-percent sample in each compartment. However, all harvested trees have been tallied individually throughout this study to generate yield data. Logging crews made separate tallies of all trees that were not marked for cutting but were damaged and subsequently cut during timber harvesting. We now calculate the residual stand structure following each periodic harvest based on the 10-percent cruise prior to harvesting minus the harvest tally once the data have been standardized to a per unit area. Therefore, residual stand structures are estimates rather than based on a 100-percent tally, as in the early years of this study.

The change in data-collection procedures does not allow a quantitative temporal analysis of woody species diversity, though we do describe temporal changes in species composition. Seedling and sapling data have been collected in the past but were not collected during the last cycle of periodic harvests and are not evaluated here. Volume estimates used in our analysis were generated from local volume tables developed from sites throughout the Fernow. Originally, volume tables were constructed for each research compartment. In 1971, board foot volume tables (International ¼ inch rule) were revised based on SI and species. All board foot volumes reported here were calculated on the basis of 1971 species-specific tables for northern red oak SI 70. Periodically, and most recently in 2002, volume tables were checked for validity; they continue to serve as useful estimators of actual tree volume based on actual scale comparisons.

## Data Analysis

Repeated measures modeling using restricted maximum likelihood via SAS PROC MIX (SAS Inst. 2001) was used to evaluate treatment effects related to harvest period for yield in board feet/acre/year (BDFT), residual basal area in $ft^2$/acre (RBA), and percentage of grade 1 butt logs (GRADE1) removed at each harvest. To maintain a balanced design, the first three harvests were used from each compartment for analysis. When data from four harvests were available, we also evaluated the results graphically and have included them. Treatment level and harvest period were considered fixed effects in the model. To determine the best covariance structure for our data, we used the Akaike Information Criteria (AIC) and Schwarz's Bayesian Criterion (BIC) (Gregoire and others 1995; Littell and others 1996). The error covariance structure with the smallest values of AIC and BIC was considered the best model. In repeated measures analysis, the appropriate specification of the error covariance structure is an important part of the model

Table 2.—Harvested volume, residual basal area of merchantable trees (d.b.h. ≥ 11 inches), and percentage of grade 1 butt logs harvested (results are from the restricted maximum likelihood model and do not include the unreplicated harvest in 2004 from Compartment 31 (3 percent) or the fourth harvests from Compartments 26A and 26B (6 percent)

| Financial maturity rate (%) | Periodic harvest | Harvest volume | Residual basal area | Butt log grade 1 |
|---|---|---|---|---|
| | Number | Board feet/acre/year[a] | $ft^2$/acre[a] | Percent[a] |
| 6 | | 457a | 42.7a | 38.2a |
| 4 | | 358ab | 54.3a | 54.2a |
| 3 | | 316b | 51.8a | 45.5a |
| | 2 | 422a | 48.0a | 50.4a |
| | 3 | 390a | 52.1a | 54.4a |
| | 1 | 319b | 48.7a | 33.1a |
| 6 | 3 | 523a | 39.1a | 38.8a |
| 6 | 2 | 511a | 41.5a | 45.1a |
| 4 | 2 | 412ab | 53.5a | 56.9a |
| 4 | 3 | 368ab | 60.9a | 69.1a |
| 3 | 2 | 344ab | 49.1a | 49.1a |
| 6 | 1 | 336ab | 47.6a | 30.8a |
| 3 | 1 | 326ab | 49.9a | 32.0a |
| 4 | 1 | 296b | 48.6a | 36.4a |
| 3 | 3 | 278b | 56.4a | 55.4a |

[a]Means are separated within columns (α = 0.10) using the Tukey-Kramer mean comparison procedure and are designated by lower case letters.

building process because measurements over time on the same compartments often are highly correlated. We included first-order autoregressive (AR(1)), unstructured (UN), compound symmetry (CS), and spatial power (SP(POW)) covariance structures because these seemed the most appropriate from a biological perspective. The AR(1) error covariance structure provided the best fit for modeling BDFT. In all other cases, the UN error covariance structure resulted in the smallest values of AIC and BIC and the P values reported were derived accordingly.

We used the Shapiro-Wilks test and graphical analysis to test for the assumed normality of the residuals. We also plotted the residuals versus the predicted values to graphically assess the assumption of variance homogeneity. The results of our tests indicated that no transformations were needed. We used the Tukey-Kramer mean separation test to examine for individual differences in treatment level, harvest period, and interaction terms. Because of the relatively low power of the experimental design due to less than desirable replication, the alpha level for significance was set at 0.10 before tests of significance were performed. We were comfortable using a larger than normal alpha because our results were derived from typical NIPF-size operational units with noticeable variability. Also, the consequences of erroneously concluding significance were no greater than erroneously concluding no difference among treatment levels and harvest periods.

## RESULTS

### Yield

Treatment level (p = 0.0957), periodic harvest (p = 0.0069), and the interaction of treatment level and periodic harvest (p = 0.0832) were significant predictors of BDFT. The significant interaction term indicates treatment effects vary with time and that current rates may continue to vary by treatment level. Most notably, the 6-percent treatment has deviated from the other treatments after repeated harvests. Mean BDFT was 319 at the first harvest for the three financial maturity levels included in this study. BDFT increased significantly at the second and third harvest periods but more so for the

6-percent treatment reflecting the significant interaction between harvest and treatment level (Table 2). This treatment yielded more than 500 BDFT during the second and third harvests (Table 2). This equates to a yield of more than 5,000 board feet/acre/decade, well above the expected growth and yield of about 3,000 board feet/acre/decade in managed stands. Graphical analysis shows that board foot yield declined to about 4,450 acre/decade by the fourth periodic harvest in the 6-percent compartments but still was above expected productivity (Fig. 1). BDFT may have peaked during the second or third harvests (Fig. 1), though the suggested trends are not statistically significant (Table 2). The 3- and 6-percent guidelines have resulted in average harvest volumes that are meaningfully different within a management context. The 6-percent guidelines have resulted in merchantable harvests well above the expected growth, while the 3-percent guidelines currently are yielding somewhat less than the expected growth (Table 2, Fig. 1).

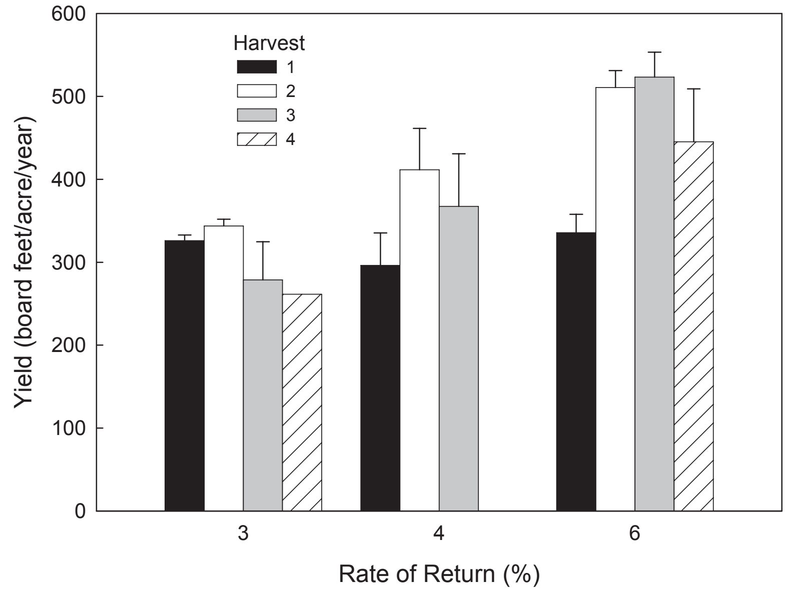


Figure 1.—Harvested board foot volume (International ¼ inch) of merchantable trees (d.b.h. ≥ 11 inches) by periodic harvest and rate-of-return treatment level (error bars = 1 standard error of the mean). Yield is presented on an annualized basis to eliminate variation associated with deviations in the 10-year harvest cycle. The error bar was intentionally omitted for the fourth periodic harvest of the 3-percent treatment because it has not yet been replicated.

## Residual Basal Area

Treatment effects regarding RBA were not significantly different. The RBA of sawlog-size trees did not differ by treatment (P = 0.5956), harvest cycle (P = 0.1578), or the interaction of these two factors (P = 0.5694). It is noteworthy that RBA model estimates for all but two treatment and harvest cycle combinations were below the recommended minimum of 55 $ft^2$/acre (Table 2). Of the 21 documented individual harvests that have occurred to date in this study, only 9 have resulted in residual basal area levels above 55 $ft^2$/acre, and none exceeded the recommended maximum of 70 $ft^2$/acre (Fig. 2). Of the eight harvests at the 6-percent level, only one resulted in a residual basal area above 55 $ft^2$/acre. These results imply that the 6-percent level is unlikely to result in a residual stand within the recommended

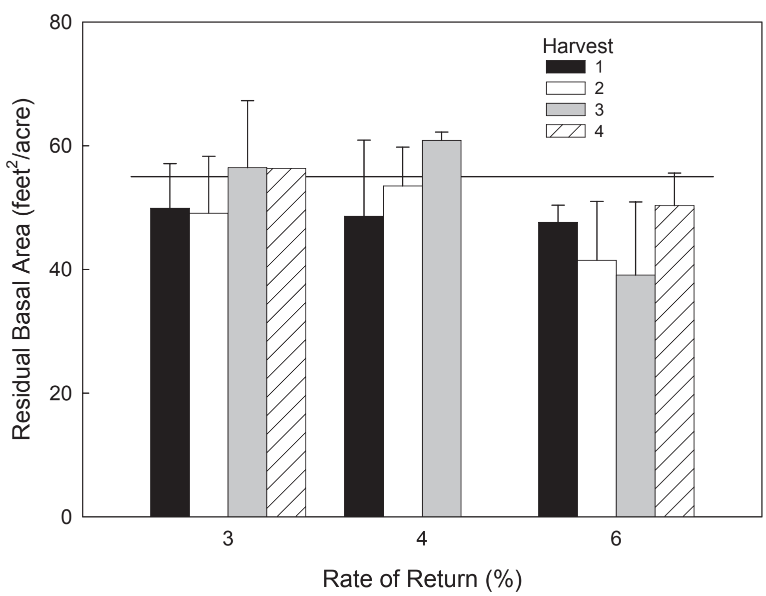


Figure 2.—Residual basal area of sawlog-size trees (d.b.h. ≥ 11 inches) by periodic harvest and rate of return treatment level (error bars = 1 standard error of the mean). Horizontal line identifies minimum residual basal area (55 $ft^2$/acre) as recommended by Trimble and others (1974). The error bar was intentionally omitted for the fourth periodic harvest of the 3-percent treatment because it has not been yet been replicated.

range for residual stocking. The RBA of all trees with a d.b.h. of 5 inches or greater did not differ by treatment (P = 0.4874), harvest cycle (P = 0.4347), or the interaction of these two factors (P = 0.2915). When we included pole-size trees in our calculations, the mean RBA for all compartments through time was 75.9 $ft^2$/acre (SE = 2.7, n = 21) and ranged from 94.8 to 50.4 $ft^2$/acre (Fig. 3). The average difference in RBA between sawlog only and pole-size and larger trees was 25.9 $ft^2$/acre across all treatments and harvest cycles (n = 21). We do not know whether the substantial amount of pole-size RBA can mitigate the presumed less than desired sawlog-size RBA.

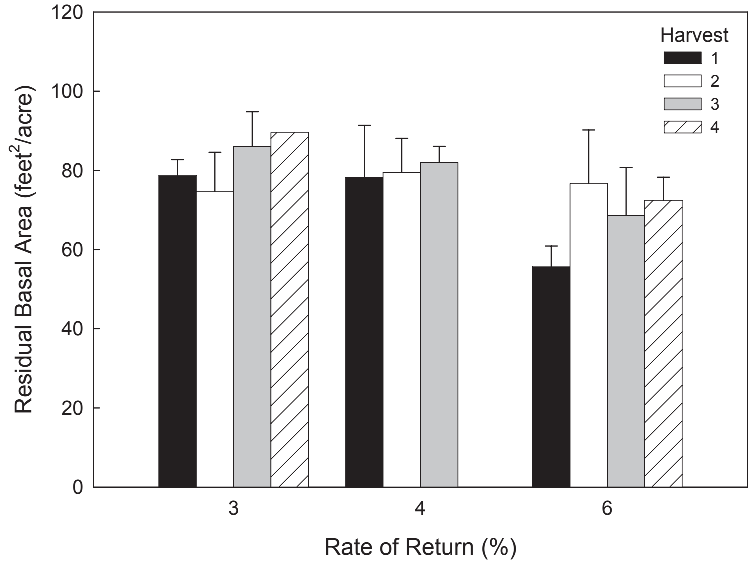


Figure 3.—Residual basal area of both pole-size ( 10.9 ≥ d.b.h. ≥ 5 inches) and sawlog-size trees (d.b.h. ≥ 11.0 inches) by periodic harvest and rate-of-return treatment level (error bars = 1 standard error). The error bar was intentionally omitted for the fourth periodic harvest of the 3-percent treatment because it has not yet been replicated.

## Log Grade

Estimates of GRADE1 generated by our analysis ranged from about 38 percent for the 6-percent treatment to 54 percent for the 4-percent treatment (Table 2), but there was no evidence of a statistical difference among treatments (P = 0.3377), harvest cycles (P = 0.1836), or the interaction of these two factors (P = 0.6794). GRADE1 model estimates were about 54 percent for the most recent harvest cycle and about 33 percent for the first periodic harvest. Graphically, when the data from the fourth harvest are included, it is suggested that butt-log quality has improved during the life of this study and that the 3- and 4-percent treatments produce a greater proportion grade 1 butt logs than the 6-percent treatment (Fig. 4).

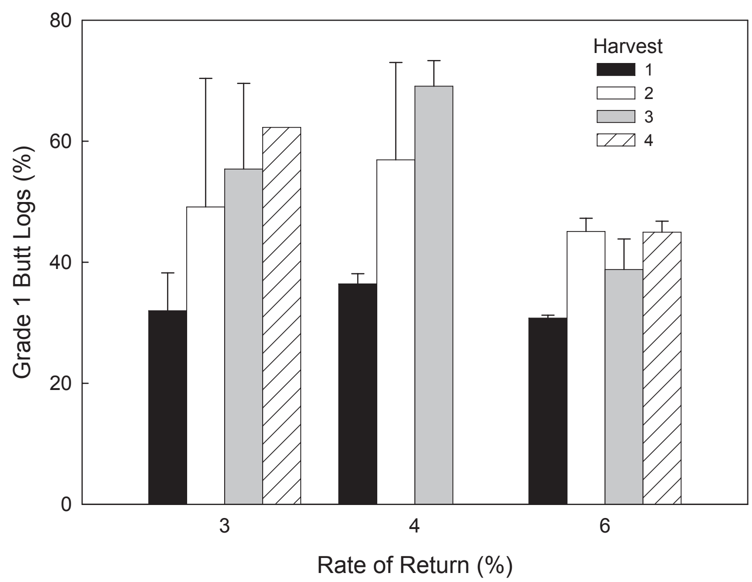


Figure 4.—Percentage of grade 1 butt logs harvested by periodic harvest and rate-of-return treatment level (error bars = 1 standard error). The error bar was intentionally omitted for the fourth periodic harvest of the 3-percent treatment because it has not yet been replicated.

## Species Composition

Woody plant communities were complex and consisted of 31 commercial species. A comparison of beginning and ending species composition revealed several trends. First, all three treatments resulted in a decline in intolerant species, most notably in oak/hickory but also in black cherry/yellow-poplar and "other-intolerant" categories (Fig. 5). The latter included sassafras (*Sassafras albidum* (Nutt.) Nees), black locust (*Robinia pseudoacacia* L.),

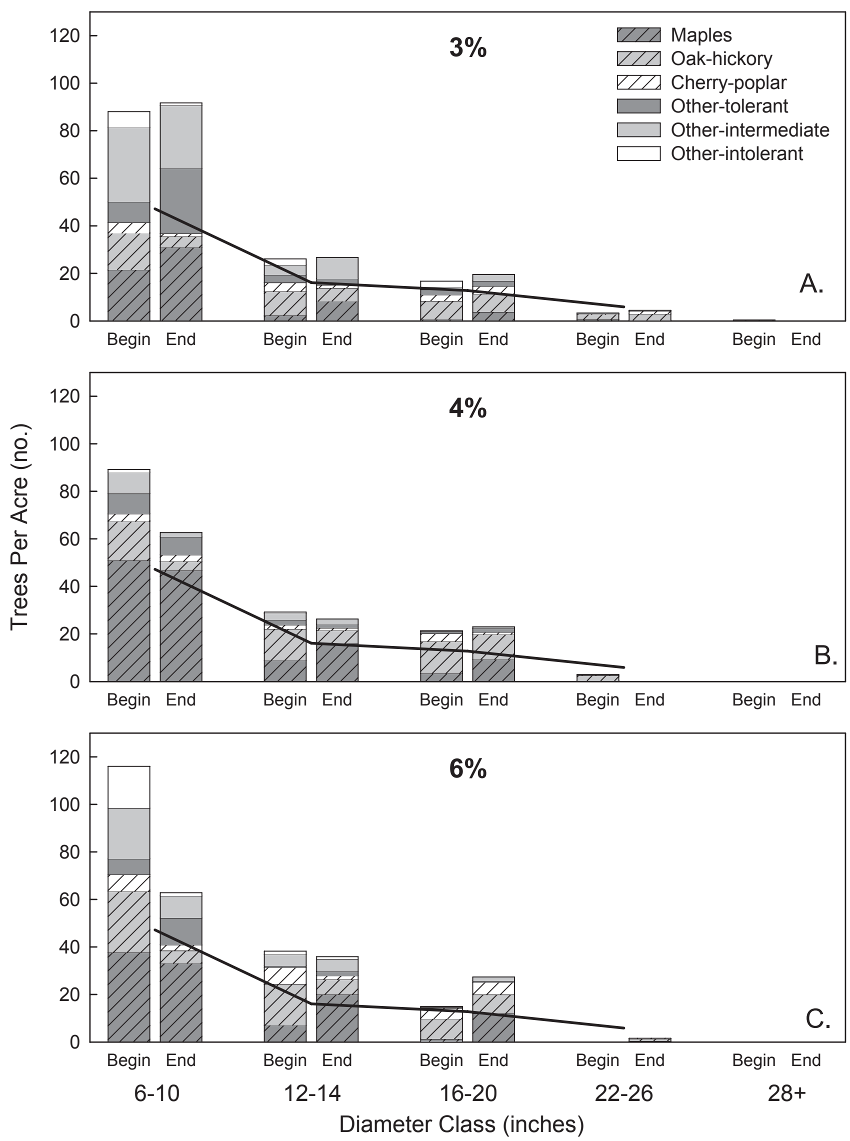


Figure 5.—Distribution of species groups by diameter class prior to treatment initiation and the last remeasurment. Segmented line approximates the residual stand structure defined by the BDq approach to single-tree selection: "q" of 1.3 (2-inch d.b.h. classes), a residual basal area "B" of 70 $ft^2$/acre for pole-size trees and greater (which equates to about 54 $ft^2$/acre for sawlog-size trees), and the largest tree to retain in the stand "D" of 26 inches d.b.h.

bigtooth aspen (*Populus grandidentata* Michx.), butternut (*Juglans cinerea* L.), and fire cherry (*Prunus pensylvanica* L. f.). The 6-percent treatment, which resulted in the lowest average RBA, showed a drop of intolerant trees from about 25 to fewer than 4 per acre in the 6- to 10-inch diameter class from the first to the last inventory cycles. The proportion of shade-intolerant species was not greater in the 6-percent treatment than in the other treatments (Fig. 5A-C).

As noted, the oak/hickory category also is in decline. When this study was initiated, the size-class distribution for oak/hickory was similar for all three treatments, with the smallest class consisting of the most stems and progressively fewer stems in larger classes. Currently, oak/hickory is most abundant in the 16- to 20-inch diameter class with progressively fewer stems in smaller classes, indicating that oak/hickory is responding as a cohort and is not being sustained as individual stems become older and larger (Fig. 5). As with intolerant species, the decline of oak/hickory is most evident in the pole-size class. During the first inventory, oak/hickory ranged from 15 to 25 stems per acre in the pole class across all compartments. After at least three periodic harvests, pole-size oak/hickory ranged from four to five stems per acre. Northern red and chestnut oak were most common but other species also present were white (*Q. alba* L.), scarlet (*Q. coccinea* Muenchh.), and black oak (*Q. velutina* Lam.), and shagbark (*Carya ovata* (Mill.) K. Koch) and bitternut hickory (*C. cordiformis* (Wangenh.)

K. Koch). Oaks remain well represented in the sawtimber classes, but with average growth rates of about 2 inches per decade, their ultimate decline is nearly assured. Informal regeneration surveys indicate that this species group is virtually absent from the seedling and sapling layers in every compartment. Other species classified as intermediate in shade tolerance include black (*Betula lenta* L.) and yellow birch (*B. alleghaniensis* Britton), slippery elm (*Ulmus rubra* Muhl.), cucumbertree, Fraser magnolia (*M. fraseri* Walt.), serviceberry (*Amelanchier arborea* (Michx. f.) Fern), sourwood (*Oxydendrum arboreum* L.), and white ash. Of these, black birch has the potential to be an interfering species in understories of partially disturbed canopies and was the most common species in the pole class when the 3-percent compartments were last remeasured (Fig. 5A).

Offsetting the declines noted, the density of shade-tolerant species increased for all three treatments (Fig. 5). The maples were most prominent in this category and commercially important sugar maple on average was more than twice as abundant as red maple. Pole-size sugar maple averaged about 25 stems/acre across all compartments at the last measurement cycle. Pole-size American beech had about the same average density as red maple throughout the study area but the response of American beech to treatments varied considerably across experimental units. For example, pole-size American beech was abundant in Compartment 31 but nearly absent in Compartments 60 and 20B. Other tolerant species included eastern hemlock (*Tsuga canadensis* (L.) Carr.), ironwood (*Ostrya virginiana* (Mill.) K. Koch), striped maple (*A. pensylvanicum* L.), basswood, blackgum (*Nyssa sylvatica* Marsh.), and flowering dogwood (*Cornus florida* L.). Dogwood (d.b.h. ≥ 5.0 inches) no longer was present in any compartment during the most recent inventory cycle.

## DISCUSSION

Trimble and others (1974) outlined numerous issues to evaluate the FMDL system for managing hardwood stands in the central Appalachians. We address several of these issues here with the insight obtained after more than three decades of experience and empirical results. First, can this system of marking provide an adequate stand structure for approximately equal cuts and regular intervals? Balancing growth with removal is a fundamental principal of all uneven-age silviculture and an important component of the FMDL approach to regulation of timber harvests. In addressing this point, we reiterate that the rate of return at each periodic harvest was not adjusted to meet RBA goals as has been suggested previously by Trimble and others (1974) and Miller and Smith (1993). However, our results provide insight into the association between stocking and productivity that could not have been achieved otherwise.

On average, all three rate of return guidelines studied were at or exceeded the anticipated level of productivity (about 300 board feet/acre/year) for the duration of the study (Table 2). However, because there was a significant interaction between the rate of return (treatment level) and periodic harvest (time), it is not clear whether the average rates of return for each treatment level can be sustained following additional periodic harvests at regular intervals. The second and third harvests generally yielded more merchantable volume than the first harvest, but the fourth harvests in the 3- and 6-percent treatments suggest a possible downward trend in productivity (Fig. 1). Changes in productivity over time might be related to several factors, including changes in species composition and/or stocking.

The residual stand basal area for sawlog-size trees usually was at the lower limit or below the recommended range (55 to 70 $ft^2$/acre) for all rates of return. Had we been adhering to the recommendation to lower the rate-of-return marking guidelines to have a minimum of 55 $ft^2$/acre following harvest, the 6-percent marking guidelines would have been inapplicable. Conversely, there was no instance in which any marking guideline resulted in a residual stand that exceeded the recommended maximum RBA.

Because productivity was at or above expected levels and RBA generally was below a desired range, we compared postharvest stand structure by treatment level to residual stand parameters used with the BDq approach to single-tree selection elsewhere on the Fernow (Fig. 5A-C) for SI 70 (Smith and Lamson 1982). The BDq parameters used

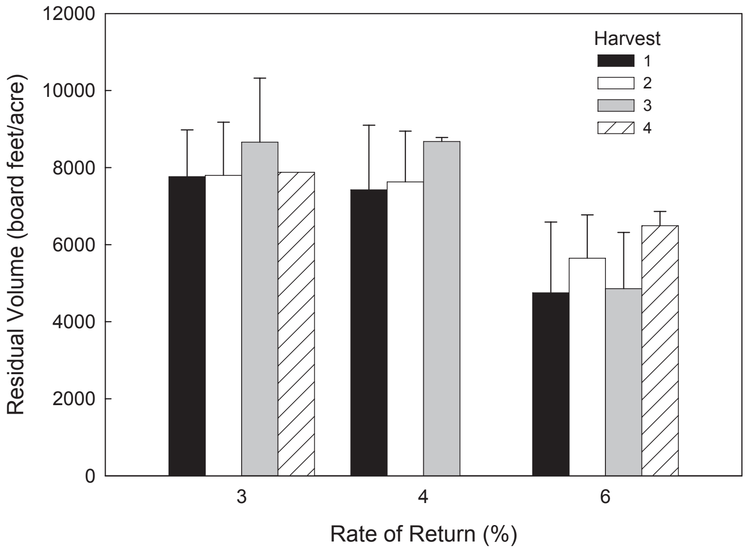


Figure 6.—Residual board foot volume (International ¼ inch) of merchantable trees (d.b.h. ≥ 11 inches) by periodic harvest and rate-of-return treatment level (error bars = 1 standard error). The error bar was intentionally omitted for the fourth periodic harvest of the 3-percent treatment because it has not yet been replicated.

for comparison included a "q" of 1.3, a residual basal area "B" of 70 $ft^2$/acre for pole-size trees and greater (which equates to about 54 $ft^2$/acre for sawlog-size trees), and the largest tree to retain in the stand "D" of 26 inches d.b.h. Similar BDq parameters have been used for more than a half century in other studies on the Fernow (Schuler 2004). Using these guidelines for comparison, the stands evaluated in this study had surplus trees in all but the largest diameter classes evaluated (22 to 26 inches d.b.h.). These are above the maximum in the 6-percent rate-of-return and limited by prescription in the 4-percent rate-of-return (Fig. 5). Moreover, the RBA of pole-size trees and greater was at or above 70 $ft^2$/acre in most cases (Fig. 3). Our results compared to the single-tree selection residual stand goal suggest that the recommended RBA range of 55 to 70 $ft^2$/acre for sawlog-size trees may be unrealistically high when pole-size trees occupy 25 $ft^2$/acre as documented in this study. RBA below 55 $ft^2$/acre should be acceptable so long as productivity can be sustained at or above the desired levels and there is no significant erosion of residual stand volume or butt log grade deterioration. RBA guidelines originally proposed by Trimble and others (1974) were based on expert opinion at that time and have not been validated.

A trend in declining residual volume after harvesting indicates that more volume is being removed than the site was capable of producing during a given cutting cycle and that sustainable harvest levels are being exceeded. Standing volume after harvest is an important element of the *plenter* system, a form of uneven-age silviculture used successfully in central Europe (Schütz 1999). An *a posteriori* analysis of residual standing volume revealed no evidence of a postharvest erosion of standing volume over time (Fig. 6). The 3- and 4-percent treatments have developed similar characteristics and have residual merchantable volumes of 8,000 to 9,000 board feet/acre, while the 6-percent treatment averaged about 6,500 board feet/acre after the last periodic harvest. Also, the replicated treatments showed trends of increasing residual board foot volume after each periodic harvest. These findings suggest that the originally proposed basal area guidelines are too high and that levels of RBA less than 55 $ft^2$/acre are acceptable and may be even closer to optimal with respect to periodic yield of board foot volume. Optimal levels of stocking for high-quality sawlog production have not been defined for mixed hardwood stands in the central Appalachians. Additional study of residual stocking is needed to increase our understanding of the maximum sustained yield of various forest products.

Equal in importance for timber management is the quality of sawlogs being produced. In this study, the proportion of trees harvested with grade 1 butt logs was similar to that in stands managed by single-tree selection (Wiemann and others 2004) and exceeded 50 percent for the most recent harvests in the 3- and 4-percent treatments. On the Monongahela National Forest, timber sales with less than half of the trees meeting criteria for grade 1 butt logs are reduced in value during the timber appraisal process. Maintaining desirable tree- and log-quality characteristics may be become more difficult as shade-intolerant species are depleted through continued periodic harvests. Throughout the central Appalachians, uneven-age management of any form postdates the establishment of even-age stands in virtually every case. As such, stands managed by uneven-age methods retain even-aged, shade-intolerant species for a period of time that presumably should have better butt-log quality than stems of shade-tolerant species established in small canopy gaps. The experimental compartments used in this study are no exception. As the shade-tolerant species replace the remaining shade intolerants, it is reasonable to assume that butt-log quality may decline over time, though we found no evidence of this. In the future, it may be necessary to manage more aggressively for butt-log quality than current guidelines suggest. Sugar maple managed in uneven-aged stands has better but-log quality than sugar maple in unmanaged reference stands (Wiemann and others 2004).

The concept of FMDL selection (as well as all uneven-age management) is based on the idea that desirable trees can be recruited and developed into larger size classes through repeated harvests. This requires having desirable species that can survive and grow in an environment dominated by relatively small canopy gaps created by the harvesting of mostly single trees and the creation of small openings. In the 1970s it was understood that uneven-age management using single-tree selection could achieve adequate regeneration and development of both red and sugar maple and American beech (Trimble and others 1974; Smith 1980). It was not known whether the FMDL guidelines tested in this study would result in the unplanned creation of openings large enough to recruit and sustain a greater proportion of shade-intolerant species that initially dominated the canopies of these stands. Our results point out that even with RBA below what has been previously recommended, the preponderance of stems reaching pole size are shade-tolerant species. Not even the 6-percent treatment deviated from this trend; thus, it is expected that over time the FMDL guidelines will result in stands dominated by shade-tolerant species.

Since shade-tolerant species are the predominant group moving into the pole class, the question is whether these species are acceptable. Sawlog prices in the West Virginia Timber Market Report (www.ahc.caf.wvu.edu, 26 June 2006) for the first quarter of 2006 indicate that shade-intolerant black cherry was the State's highest valued species during the reporting period at $710 per thousand board feet (Mbf), but sugar maple was the second highest valued species ($417/Mbf) and somewhat greater than red oak ($297/Mbf). Red maple listed as soft maple ($206/Mbf) was greater than white oak ($163/Mbf). Yellow-poplar, a common shade-intolerant species, was listed at $129/Mbf. Current stands with equal proportions of sugar and red maple would be valued at $312/Mbf while stands with equal proportions of black cherry, red and white oak, and yellow-poplar would be valued at $325/Mbf. Thus management efforts that favor preferred shade-tolerant species can be competitive with efforts that favor shade-intolerant species based on recent stumpage values.

Historically, prices for soft maple have been less than oak and it is not known how long the relative equality between the oaks and maples will persist. However, it is well known that oaks are difficult to regenerate in the central Appalachians, so the choices for many land managers are essentially between the shade-tolerant maples and beech, or the shade-intolerant suite of species. If the stand characteristics associated with even-age management and clearcutting are unacceptable, the potential species and associated stumpage prices associated with uneven-age management are a reasonable alternative. For example, using the stands observed here with average productivity for the 4-percent treatments (3,580 board feet/acre/decade), expected revenues (assuming $312/Mbf for the average maple stumpage value) on a 40-acre parcel (SI = 70) would be about $45,000 per decade.

The FMDL guidelines cannot provide a long-term solution to the regulation of merchantable harvest if undesirable species are allowed to dominate the regeneration and eventually dominate the stand. In this study, American beech represented more than 30-percent of all pole-size stems in one of six compartments so treatment is needed to reduce this percentage. American beech may be able to provide some mast production in stands using uneven-age management but this is a low-value commercial species with a bleak future due to beech bark disease (Houston 1994). American beech and striped maple also interfere with the establishment of more valuable species (Nyland and others 2006). Kochenderfer and others (2004) developed recommendations for preharvest manual herbicide treatments to control unwanted beech. Average application costs were less than $40/acre when treating as many as159 pole-size stems/acre. Treating pole-size trees with stem-injected glyphosate also controlled half of the small understory American beech stems. When American beech dominates the understory in stands that are partially cut, it is likely to be the dominant regeneration after the harvesting is completed (Leak 1988; Bohn and Nyland 2003). Nyland and others (2006) recommend controlling undesirable advance regeneration with herbicides if more than 30 to 40 percent of the area has competitive beech or striped maple.

## CONCLUSION

Using a silvicultural practice that provides a continuous output of desired products without degrading the site for future productivity is a basic tenet of sustainable forestry. In this study, our objective was to determine if FMDL selection can sustain the production of high-quality sawlog timber. We evaluated periodic board foot yield, residual basal area, percentage of grade 1 butt logs, and species composition over time. On the basis of the combined results to date, we believe that the financial maturity diameter-limit method can be sustainable if applied appropriately. Unlike earlier recommendations, we believe that a minimum RBA of about 45 $ft^2$/acre in sawlog-size trees is acceptable on good sites (northern red oak SI 70) without eroding the potential to maintain harvest intervals and volumes, presuming about 20 $ft^2$/acre of desirable pole-size trees is also present. Research is needed to refine guidelines for desired residual stocking for all site indices. Our results suggest that the 6-percent treatment and possibly other treatments may not be feasible with earlier recommendations regarding minimum RBA of sawlog-size trees.

Combining the FMDL guidelines with treatment of interfering regeneration would addresses certain concepts of sustainable forestry. Improving on the common form of diameter-limit harvesting using the procedures described here would be a significant step in improving forest management throughout the Eastern United States.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

Braun, E.L. 1950. **Deciduous forests of Eastern North America.** Philadelphia, PA: Blakiston Co. 596 p.

Buongiorno, J. K.; Vasievich, M. 2000. **Economic and ecological effects of diameter-limit and BDq management regimes: simulation results for northern hardwoods**. Silva Fennica. 34(3): 223-235.

Buongiorno, J.; Schultz, B.J.; Skog, K.E. 2004. **Quantifying trade-offs between economic and ecological objectives in uneven-aged mixed-species forests in the Southern United States.** Gen. Tech. Rep. FPL-145. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 5 p.

Erdmann, G.G.; Oberg, R.R. 1973. **Fifteen-year results from six cutting methods in second-growth northern hardwoods.** Res. Pap. NC-100. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 12 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. 96: 33-39.

Gregoire, T.G.; Schabenberger, O.; Barrett, J.P. 1995. **Linear modeling of irregularly spaced, unbalanced, longitudinal data from permanent-plot measurements.** Canadian Journal of Forest Research. 25: 137-156.

Gilliam, F.S.; Turrill, N.L.; Adams, M.B. 1995. **Herbaceous-layer and overstory species in clear-cut and mature central Appalachian hardwood forests.** Ecological Applications. 5(4): 947-955.

Grisez, T.J.; Mendel, J.J. 1972. **The rate of value increase for black cherry, red maple, and white ash.** Res. Pap. NE-231. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 26 p.

Houston, D.R. 1994. **Major new tree disease epidemics: beech bark disease.** Annual Review of Phytopathology. 32: 75-87.

Kenefic, L.S.; Sendak, P.E.; Brissette, J.C. 2005. **Comparison of fixed diameter-limit and selection cutting in northern conifers.** Northern Journal of Applied Forestry. 22(2): 77-84.

Kochenderfer, J.D.; Kochenderfer, J.N.; Warner, D.A.; Miller, G.W. 2004. **Preharvest manual herbicide treatments for controlling American beech in central West Virginia.** Northern Journal of Applied Forestry. 21(1): 40-49.

Littell, R.C.; Milliken, G.A.; Stroup, W.W.; Wolfinger, R.D. 1996. **SAS system for mixed models.** Cary, NC: SAS Institute. 633 p.

McGill, D.W.; Westfall, M.A.; Gartin, S.A.; O'Dell, K.S.; Boone, H.N. 2004. **Identifying priority forest management issues in West Virginia—s survey of state service foresters at various administrative levels**. In: Yaussy, D.; Hix, David M.; Long, Robert P.; Goebel, P. Charles, eds. Proceedings, 14th central hardwood forest conference; 2004 March 16-19, Wooster, OH. Gen. Tech. Rep. NE-316, Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 282-286. [CD-ROM].

McNab, W.H.; Avers, P.E. 1994. **Ecological subregions of the United States: section descriptions.** Admin. Publ. WO-WSA5. Washington, DC: U.S. Department of Agriculture, Forest Service. 267 p.

Mendel, J.J.; Trimble, G.R. 1969. **The rate of value increase for yellow-poplar and beech.** Res. Pap. NE-140. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 27 p.

Mendel, J.J.; Grisez, T.J.; Trimble, G.R. 1973. **The rate of value increase for sugar maple.** Res. Pap. NE-250. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 27 p.

Miller, G.W. 1993. **Financial aspects of partial cutting practices in central Appalachian hardwoods.** Res. Pap. NE-673. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 9 p.

Miller, G.W.; Smith, H.C. 1991. **Comparing partial cutting practices in central Appalachian hardwoods.** In: McCormick, L.H.; Gottschalk, K.W., eds. Proceedings: 8th central hardwood forest conference; 1991 March 3-6, University Park, PA. Gen. Tech. Rep. NE-148, Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 105-119.

Miller, G.W.; Smith, H.C. 1993. **A practical alternative to single-tree selection?** Northern Journal of Applied Forestry. 10(1): 32-38.

Niese, J.N.; Strong, T.F.; Erdmann, G.G. 1995. **Forty years of alternative management practices in**

**second-growth, pole-size northern hardwoods. II. Economic evaluation.** Canadian Journal of Forest Research. 25(7): 1180-1188.

Nyland, R.D. 1992. **Exploitation and greed in eastern hardwood forests.** Journal of Forestry. 90(1): 33-37.

Nyland, R.D. 2005. **Diameter-limit cutting and silviculture: a comparison of long-term yields and values for uneven-aged sugar maple stands.** Northern Journal of Applied Forestry. 22(2): 111-116.

Orr, B.D.; Reed, D.R.; Mroz, G.D. 1994. **Three basal area level harvest trials in uneven-aged northern hardwoods.** Northern Journal of Applied Forestry. 11(4): 117-123.

Pan, C.; Tajchman, S.J.; Kochenderfer, J.N. 1997. **Dendroclimatological analysis of major forest species of the central Appalachians.** Forest Ecology and Management. 98: 77-87.

SAS Institute, Inc. 2001. **SAS user's guide: statistics. Version 8.** Cary, NC: SAS Institute.

Schnur, G. L. 1937. **Yield, stand, and volume tables for even-aged upland oak forests.** Tech. Bull. 560. Washington, DC: U.S. Department of Agriculture. 85 p.

Schuler, T.M.; Fajvan, M.A. 1999. **Understory tree characteristics and disturbance history of a central Appalachian forest prior to old-growth harvesting.** Res. Pap. NE-710. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p.

Schütz, J.P. 1999. **The Swiss experience: more than one hundred years of experience with a single-tree selection management system in mountainous mixed forests of spruce, fir and beech from an empirically developed utilization in small-scale private forests to an elaborate and original concept of silviculture.** In: Emmingham, W.H., comp. Proceedings, IUFRO interdisciplinary uneven-aged management symposium; September 1997; Corvallis, OR. Corvallis, OR: Oregon State University: 21-34.

Smith, H.C. 1980. **An evaluation of four uneven-aged cutting practices in the southern Appalachians.** Southern Journal of Applied Forestry. 4(4): 193-200.

Smith, H.C. 1991. **Managing hardwoods, alternative to single-tree selection "how to".** Proceedings, uneven-aged management of hardwoods in the northeast; 1991 April 9-10; Lambertville, NJ. Society of American Foresters, New Jersey Division: 66-74.

Smith, H.C.; Lamson, N.I. 1982. **Number of residual trees: a guide for selection cutting.** Gen. Tech. Rep. NE-80. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 33 p.

Sokol, K.A.; Greenwood, M.S.; Livingston, W.L. 2004. **Impacts of long-term diameter-limit harvesting on residual stands of red spruce in Maine.** Northern Journal of Applied Forestry. 21: 69-73.

Strong, T.F.; Erdmann, G.G.; Niese, J.N. 1995. **Forty years of alternative management practices in second-growth, pole-size northern hardwoods. I. Tree quality development.** Canadian Journal of Forest Research. 25(7): 1173-1179.

Trimble, G.R.; Mendel, J.J. 1969. **The rate of value increase for northern red oak, white oak, and chestnut oak.** Res. Pap. NE-129. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 29 p.

Trimble, G.R.; Mendel, J.J.; Kennell, R.A. 1974. **A procedure for selection marking hardwoods combining silvicultural considerations with economic guidelines.** Res. Pap. NE-292. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 33 p.

Trimble, G.R.; Weitzman, S. 1956. **Site index studies of upland oaks in the northern Appalachians.** Forest Science. 2: 162-173.

U.S. Department of Agriculture, Soil Conservation Service. 1967. **Soil survey of Tucker County, West Virginia.** Elkins, WV: U.S. Department of Agriculture, Soil Conservation Service.

Volin, V.C.; Buongiorno, J. 1996. **Effects of alternative management regimes on forest stand structure, species composition, and income: a model for the Italian Dolomites.** Forest Ecology and Management. 87(1-3): 107-125.

Ward, J.S.; Stephens, G.R.; Ferrandino, F.J. 2005. **Influence of cutting method on stand growth in sawtimber oak stands.** Northern Journal of Applied Forestry. 22(1): 59-67.

Weitzman, S. 1949. **The Fernow Experimental Forest.** Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 16 p.

Wiemann, M.C.; Schuler, T.M.; Baumgrass, J.E. 2004. **Effects of uneven-aged and diameter-limit management on West Virginia tree and wood quality.** Res. Pap. FPL-621. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 16 p.

## APPENDIX

**Marking Guidelines for FMDL Method by Rate-of-Return, Northern Red Oak SI, and Species**

| | Mark trees of these 2-inch d.b.h. classes and larger[a] | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low return (2%) | | | Medium-low return (3%) | | | Medium return (4%) | | | Medium-high return (5%) | | | High return (6%) | | |
| Species | SI 80 | SI 70 | SI 60 | SI 80 | SI 70 | SI 60 | SI 80 | SI 70 | SI 60 | SI 80 | SI 70 | SI 60 | SI 80 | SI 70 | SI 60 |
| Yellow-poplar | 26 | 26 | 24 | 24 | 22 | 22 | 20 | 18 | 18 | 20 | 18 | 18 | 18 | 18 | 18 |
| Beech | 24 | 22 | 22 | 22 | 20 | 20 | 20 | 18 | 18 | 20 | 18 | 18 | 18 | 18 | 18 |
| Black cherry | 32 | 30 | 30 | 28 | 26 | 24 | 22 | 20 | 18 | 20 | 20 | 18 | 18 | 18 | 18 |
| Red maple | 32 | 30 | 30 | 28 | 26 | 24 | 22 | 22 | 18 | 20 | 20 | 18 | 18 | 18 | 18 |
| White ash | 30 | 28 | 28 | 26 | 24 | 24 | 22 | 20 | 18 | 20 | 20 | 18 | 18 | 18 | 18 |
| Sugar maple | 32 | 32 | 30 | 28 | 28 | 24 | 22 | 22 | 18 | 20 | 20 | 20 | 20 | 18 | 18 |
| Red oak | 26 | 26 | 24 | 24 | 24 | 22 | 22 | 22 | 20 | 22 | 20 | 20 | 20 | 18 | 18 |
| White oak | 24 | 22 | 20 | 22 | 20 | 20 | 20 | 18 | 18 | 20 | 18 | 18 | 18 | 18 | 18 |
| Chestnut oak | 24 | 24 | 22 | 22 | 22 | 20 | 20 | 18 | 18 | 20 | 18 | 18 | 18 | 18 | 18 |
| Other long-lives species | 26 | 26 | 24 | 24 | 24 | 22 | 20 | 20 | 18 | 20 | 20 | 18 | 18 | 18 | 18 |

[a] These trees will be marked unless a potential grade improvement can be foreseen in the next 10 years.

**Improvement cut for all situations, mark (above 11 inches d.b.h.):**

1. Culls and near culls (50 percent rot or nearly so in the butt log).
2. Trees with significant rot in the butt log (e.g., 40 percent and will increase to cull status by next periodic cut).
3. Very low-vigor trees.
4. Extremely rough trees with butt-log grade 5 (i.e., pallet and local use sawtimber).
5. Any tree more than 15 inches d.b.h. with butt-log grade 4 (i.e., unable to qualify as a grade 3 due to form defects but no rot).
6. Any short-lived species (e.g., black locust, sassafras, and butternut, unless it is unusually vigorous).

Schuler, Thomas M.; McGill, David W. 2007. **Long-term assessment of financial maturity, diameter-limit selection in the central Appalachians.** Res. Pap. NRS-2. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 16 p.

Financial maturity, diameter-limit (FMDL) selection was proposed more than three decades ago as a replacement for diameter-limit cutting. FMDL incorporates financial maturity guidelines for individual trees, high-priority removal of poor-quality trees, and guidelines for residual basal area. We provide the first long-term assessment of this practice after more than three decades of implementation. FMDL selection is evaluated in terms periodic yield of merchantable board feet, residual basal area, butt-log quality, and species composition. Recommendations for lowering the minimum residual basal area are presented. Management implications regarding controlling species composition are discussed.

KEY WORDS: *Quercus rubra*, *Acer saccharum*, uneven-age management, partial cutting

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