Influence of Cutting Method on Stand Growth in Sawtimber Oak Stands

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ABSTRACT: *Many upland oak forests in the eastern United States are approaching economic and biological maturity. A study was established in 1981–1984 in three central Connecticut forests to examine the effects of six distinct cutting methods (shelterwood, diameter limit, multiaged crop tree, high grading, silvicultural clearcut, forest preserve) on stand growth and dynamics in sawtimber oak stands. Board-foot volumes (International ¼) averaged 8.4 mbf/ac before the initial harvest. Sixty-nine percent of sawtimber trees had butt-log grades of 2 or better. Volume growth was significantly lower on high grading plots (36 bf/ac/year) than on the forest preserve, diameter limit, shelterwood, and multiaged crop tree plots (~214 bf/ac/year) through two cutting cycles. Total board-foot yield (final volumes plus harvested volumes) for the silvicultural clearcut plots (7.3 mbf/ac) was significantly lower than for uncut, shelterwood, and diameter limit cuts, 12.3, 12.5, and 13.0 mbf/ac, respectively. This study showed that three distinct cutting methods: shelterwood, multiaged crop tree, and forest preserve resulted in similar stand volume growth rates in sawtimber oak stands. The first two methods can be used by landowners who wish to generate income to offset expenses. The choice will depend on the aesthetic and regeneration goals of the landowner. Diameter-limit cutting also had similar volume rates, but it was necessary to lower the diameter limits for the second cutting cycle to maintain economically viable harvests. As a consequence, residual stand structure after the second cutting cycle was similar to that for the high grading plots. Although high grading had the highest harvested volume during the first cutting cycle, low quality of residual trees and depressed stand growth rates indicate it is not a viable option for long-term forest management.* *North. J. Appl. For. 22(1):59–67.*

Key Words: Volume growth, shelterwood, diameter limit, high grading, grade change.

Over 79% of the 52 million acres of oak-hickory forest in the northern United States are owned by nonindustrial private owners (Smith et al. 2001). For most of these owners, noncommodity amenities such as recreation, wildlife, or aesthetic enjoyment were more important than timber production (Birch 1996). Nevertheless, forest ownership incurs expenses such as real estate taxes, insurance, and protection. Nonindustrial owners may be amenable to forest management practices that provide income while retaining the desired noncommodity amenities.

Traditionally, forest management guidelines have suggested that economically mature sawtimber oak stands should be regenerated by even-aged methods (Roach and Gingrich 1968, Sander 1977, Hibbs and Bentley 1983, but see Larsen et al. 1997). Many landowners, especially those with smaller holdings, are unlikely to be interested in even-aged management that reduces aesthetic attributes by removing all large trees (Jones 1993). However, few studies have directly compared how stand development and yield development are affected by alternative methods (diameter limit cutting, high grading) of managing, or mismanaging, oak sawtimber.

Significant stand volume growth can accumulate on residual trees after regeneration harvests. Annual growth was approximately 200 bf/ac in uncut 80-year-old black oak stands in Michigan and 160 bf/ac in shelterwoods (Rudolph and Lemmien 1976). After deferment cutting in 80-year-old

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red oak in West Virginia, annual growth of 155 bf/ac was observed with only 20 ft^2/ac of residual basal area (Smith et al. 1989). Twelve northern red oak residuals/acre (24 ft^2/ac) yielded 221 bf/ac/year over 20 years in an 85-year-old southern Appalachian stand (Beck 1986). Grade reduction in residual trees after significantly reducing stocking levels (Sonderman 1984, Sander and Smith 1989, Marquis 1984) can be minimized by selecting vigorous trees (Beck 1986, Meadows 1998, Ward 2002).

Similarly, volume growth can be maintained after partial cutting or thinning (Dale 1972). Compared with unmanaged forests, stand growth and species composition of sawtimber trees was little changed after 30 years of diameter limit cutting in West Virginia (Miller and Smith 1991). Hutnik (1958) reported adequate volume growth following diameter limit cutting. Interestingly, residual stand volume after two diameter limit harvests was similar to a commercial clearcut harvested nineteen years earlier (Smith and Miller 1987). However, species composition differed between the two cutting methods.

The objective of this research was to compare stand volume growth and development among alternative management prescriptions (diameter limit cutting, high grading, multiaged crop tree, and forest preserve) in mature, sawtimber oak stands. We also examined volume yield and growth for two even-aged management methods (silvicultural clearcutting, shelterwood). Results of this study could be used by private and public foresters to select among management alternatives that best achieve the management goals of the landowner.

Study Area Descriptions

Study areas were established in 1981 (Bridgewater, CT), in 1983 (Morris, CT), and in 1984 (North Madison, CT) to examine the effect of various cutting methods on residual stand growth and hardwood regeneration (Table 1). The Bridgewater and Morris areas had not been thinned previously. The North Madison area had a salvage harvest about 1980 to remove dead and dying trees after a period of extensive gypsy moth defoliation (Robert Hart, Regional Water Authority Forester, 1998).

Soils were rocky to very rocky, fine sandy loams (Lithic Dystrochrepts) derived from gneiss, schist, and granite glacial tills. The well-drained to moderately well-drained soils were acidic to strongly acidic (pH 4.5–6.0). Elevations ranged from 370 to 930 ft mean sea level. Climatic data are from Hartford, CT (National Oceanic and Atmospheric Administration (NOAA) 1991). The area is in the northern temperate climate zone. Mean monthly temperature ranges from 25° F in Jan. to 73° F in July. There are an average of 176 frost-free days per year. Average annual precipitation is 44.4 in. per year, evenly distributed overall months.

All areas were fully stocked, upland oak forests with preharvest basal area values that ranged from 75 to 107 ft^2/ac (Table 2). Oaks accounted for over half of total basal area on all area, with white oaks predominating at North Madison and red oaks at the other two areas. Maple and birch were common on all areas, especially in the pole size class, and accounted for 26–44% of trees. Median age of harvested oaks ranged from 70 (Morris) to 86 years (Bridgewater).

Methods

One plot of each of the six cutting methods was implemented at each study area (Bridgewater, Morris, and North Madison). Individual cutting method plots ranged from 4–7 ac in area. Harvests were conducted within 1 year of the initial inventories (Table 1). Cutting methods were shelterwood, diameter limit, multiaged crop tree, high grading, silvicultural clearcut, and forest preserve. Specific cutting method guidelines were:

Shelterwood.—Stands were marked to remove 50% of basal area and 50% of upper canopy trees by cutting undesirable species and favoring retention of oak.

Diameter Limit.—All trees larger than the diameter limit were harvested. The initial diameter limit at each plot was selected to remove approximately half of the board-foot volume. The specific diameter limits for each study area are in Table 1.

Multiaged Crop Tree.—About 55 crop trees per acre were left among desirable poles and sawtimber. All other trees ≥5 in. dbh were harvested. Five crop trees per acre will be harvested and new crop trees will be selected at

Table 1. Plot characteristics for a southern New England cutting methods study

	Bridgewater	Morris	North Madison
Owner	The Nature Conservancy	White Memorial Foundation	Regional Water Authority
Location	N41°30′ W73°22′	N41°42′ W73°10′	N41°23′ W72°39′
Elevation	528 feet m.s.l.	930 feet m.s.l.	370 feet m.s.l.
Site index (50-yr)	71 feet	60 feet	57 feet
Median age of oaks	86 years	70 years	82 years
Marking guide for initial diameter limit treatment			
Oak	24 inches	17 inches	16 inches
Other	14 inches	14 inches	14 inches
Initial inventory	Autumn 1981	Summer 1983	Summer 1984
Second inventory	Winter 1998–99	Winter 1999–2000	Winter 1998–99
Third inventory	Autumn 2001	Autumn 2001	Autumn 2001
Initial harvest	Winter 1982–83	Autumn 1984	Winter 1984–85
Second harvest	Spring 2001	Winter 2001–01	Autumn 2000

Table 2. Initial stand characteristics of study areas by species groups for a southern New England cutting methods study. See text for species group descriptions.

Species groups	Bridgewater	Morris	North Madison
	Basal area (ft^2/acre)		
Red oaks	44.5	46.4	13.6
White oaks	28.2	12.9	25.8
Birch	12.4	9.8	9.2
Maple	5.5	19.0	11.4
Other	14.2	18.8	15.0
Total basal area	104.7	106.9	75.0
	Density (stems/acre)		
Red oaks	40.5	46.3	15.1
White oaks	27.0	16.8	31.0
Birch	24.6	20.6	18.7
Maple	15.7	55.1	26.2
Other	49.9	34.2	35.0
Total density	157.6	172.9	126.0

10- to 20-year intervals. Concurrently, all other trees ≥5 in. dbh were harvested.

High Grading.—All merchantable trees ≥11 in. dbh were harvested. Cull trees were not harvested.

Silvicultural Clearcut.—All residual trees >2 inches dbh were cut after sawtimber and cordwood harvests.

Forest Preserve.—No cutting except for a skid road in the North Madison plot.

The multiaged crop tree treatment was the first step of converting a relatively even-aged stand into a multiaged stand. Therefore, crop trees were selected by diameter classes rather than by age. With time, we hope to convert these stands to multiaged crop tree stands. This cutting method is designed to favor selected crop trees for the production of high-value timber or veneer logs while periodically removing all other merchantable material. This system may be useful for small accessible tracts where a market for fuelwood exists. Initiating this cutting method requires selection of approximately 55 potential crop trees, per acre from existing pole and sawtimber. Preference was given to desirable species (oak > pine > sugar maple > birch > beech > red maple), single stems, and excellent form. The goal was to have an even distribution of diameters overall classes. Subsequent harvests are at 10- to 20-year intervals providing flexibility to accommodate market conditions and growth. At each harvest, eight to 10 new standards per acre are chosen in the pole size class. Concurrently, one-fifth of the largest crop trees are harvested along with all other stems larger than 5 in. dbh.

All stems (≥1 in. dbh) were inventoried before harvest using 5–8 prism points (10 factor) per cutting method plot. Points were placed randomly and then permanently marked using treated stakes and stone cairns. Prism trees (those tallied as in using the prism) were banded at 4.5 ft and numbered with paint. The distance and azimuth from the prism point to each prism tree were recorded to facilitate relocation. The following data were measured for all trees: species, diameter (0.1 in.), live crown ratio (in 10% increments), crown class, and total height (ft). Pulpwood height (feet), and cubic-foot cull (10%) were measured for all trees ≥4.5 in. dbh. Additional measurements for sawlog trees (≥11 in. dbh) included: sawlog height (feet), board-foot cull (10%), and buttlog grade. The status of each tree (cut, dead, alive) was noted 1 year after the initial harvests. Standards in the Service Foresters' Handbook (Anonymous 1978) were used for minimum top diameters and to estimate grade, board-foot cull, and cubic foot cull.

In anticipation of the second cutting cycle in 2000–2001, measurements were repeated after the 1998 growing season for the Bridgewater and North Madison study areas and after the 1999 growing season for the Morris study area (Table 1). New prism trees (both ongrowth and nongrowth) were banded, numbered, and measured at that time. These trees were not included in estimates of stand volume growth. Diameter measurements were repeated at the end of the 2001 growing season, along with notation of whether the tree had been cut or damaged during the harvest operations.

Treatment guidelines for the second cutting cycle were as follows. All three of the diameter-limit plots were marked with identical specifications during the second cutting cycle to achieve commercially viable volumes. Diameter limits were 16 in. for desirable species (oaks, ash, sugar maple) and 14 in. dbh for other species. Marking guidelines for the multiaged crop tree plots were identical to those for the first cutting cycle. All stems ≥2 in. dbh were cut on the shelterwood plots after harvesting merchantable material. There was no harvesting on the high graded and silvicultural clearcut plots because volumes were not commercially viable.

Data Analysis

Tree ages were determined by counting rings on stumps of prism trees that had been cut after the initial harvest. Site indices were determined by using the upland oak curves of Schnur (1937). Only trees that originated between 1880–1920 were used to determine site index. Cubic-foot volumes were determined using formulas from Marquis (1977). Board-foot volumes (International ¼) were calculated using Scrivani (1989) with form class 78. The Scrivani algorithm was modified for any sawlog length. Basal area and volume growth at each prism point was determined using procedures in Beers and Miller (1964). Our growth estimates are somewhat conservative because they include ingrowth, but not ongrowth.

To simplify analysis and discussion, the 27 species found on the plots were grouped into five species groups: Red oaks: *Quercus coccinea*, *Q. rubra*, *Q. velutina*; White oaks: *Quercus alba*, *Q. prinus*; Maple: *Acer rubrum*, *A. saccharum*; Birch: *Betula lenta, B. alleghaniensis*, *B. papyrifera*; and Other: *Carya cordiformis*, *C. glabra*, *C. tomentosa*, *Fagus grandifolia*, *Fraxinus americana*, *Liriodendron tulipifera*, *Nyssa sylvatica*, *Pinus strobus*, *Prunus serotina*, *Sassafras albidum*, *Tsuga canadensis*, *Carpinus caroliniana*, *Castanea dentata*, *Cornus florida*, *Ostrya virginiana*, *Picea abies*, and *Juniperus virginiana*.

Data outliers brought into question the assumption of data following a normal distribution. Therefore, nonparametric statistics, which do not assume a normal distribution, were used to examine the effect of cutting method on residual basal area, total yield, and annual volume growth (Conover 1980). Nonparametric analysis also allowed each prism point to be treated as a replicate (sample) without the potential of psuedoreplication. Silvicultural clearcut plots were excluded from statistical analyses of annual basal area and volume growth.

The Kruskal-Wallis one-way analysis of variance (ANOVA) by ranks (KW) was used to test whether treatment (cutting method) was significant. When treatment effect was significant, a *z*-test was used to test for significant differences among cutting methods (Siegel and Castellan 1988, p. 213). Differences were judged significant at $P \leq 0.05$. We used Bonferroni-adjusted probabilities to maintain $P < 0.05$ for all comparisons, i.e., there is less than a 5% chance that even one of the comparisons could have been declared significant if drawn from a random population. This is a very conservative standard and may have excluded some significant differences.

Pearson χ^2 statistics were used to determine whether the distribution of cubic-foot cull classes and basal area distribution among species were independent of cutting method. To reduce the number of cells with low expected values within the contingency table, cubic-foot cull classes were reduced to four categories: <10%, 10–19%, 20–39%, and ≥40%. Similarly, red and white oak groups were combined for the analysis of pole basal area distribution among species.

ANOVA was used to examine the effects of study area and cutting method on butt log grade before and after each cutting cycle. Appropriate expansion factors were used so that mean grades were determined on a trees per acre basis, rather than as an average of only prism trees. Mean grade after the second cutting cycle included both ongrowth and nongrowth trees. Tukey's HSD test was used to test for significant differences among cutting methods. Differences were judged significant at $P \leq 0.05$.

Results

After the initial harvest, basal area was reduced by 37% on the diameter limit plots, 55% on the shelterwood and multiaged crop tree plots, 76% on the high grading plots, and 100% on the silvicultural clearcut plots (Figure 1). This reduced stocking (Gingrich 1971) to approximately 40% on the diameter limit and shelterwood plots and 30% on the multiaged crop tree plots. Oak accounted for most of the basal area on uncut (61%), shelterwood (66%), and multiaged crop tree plots (83%). Diameter limit and high grading reduced oak to only 42 and 24% of the residual basal area, respectively. Somewhat surprisingly, given the wide range of residual basal areas, there was no significant correlation between residual basal area and subsequent basal area growth. The average basal area growth was 1.4 ft^2/ac/year.

The inventories in 1998–1999 found striking differences among cutting methods in not only the absolute basal area of poletimber (Figure 2), but also in species composition ($\chi^2 = 58.0$, $df = 12$, $P \leq 0.001$). Oak accounted for over 22% of poletimber basal area on the multiaged crop tree and forest preserve plots. In contrast, oak comprised 10% or less of the poletimber basal area on the high grading and diameter limit plots.

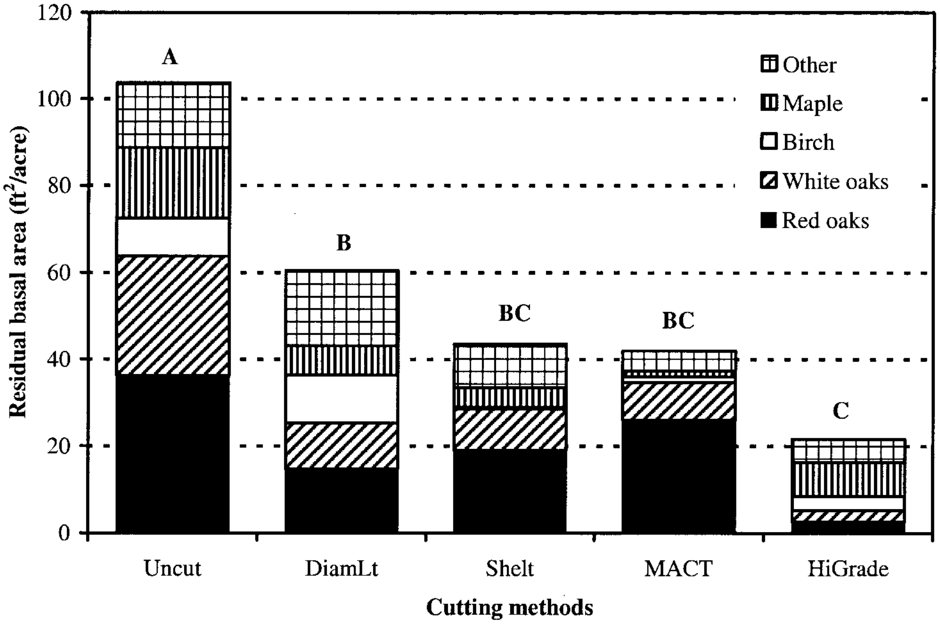

Figure 1. Residual basal area distribution (ft^2/ac) among species groups by cutting method after first cutting cycle in a southern New England study. Residual basal area values with the same letter were not significantly different at $P \leq 0.05$. Cutting methods: Uncut, forest preserve; DiamLt, diameter limit; Shelt, shelterwood; MACT, multiaged crop tree; and HiGrade, high grading.

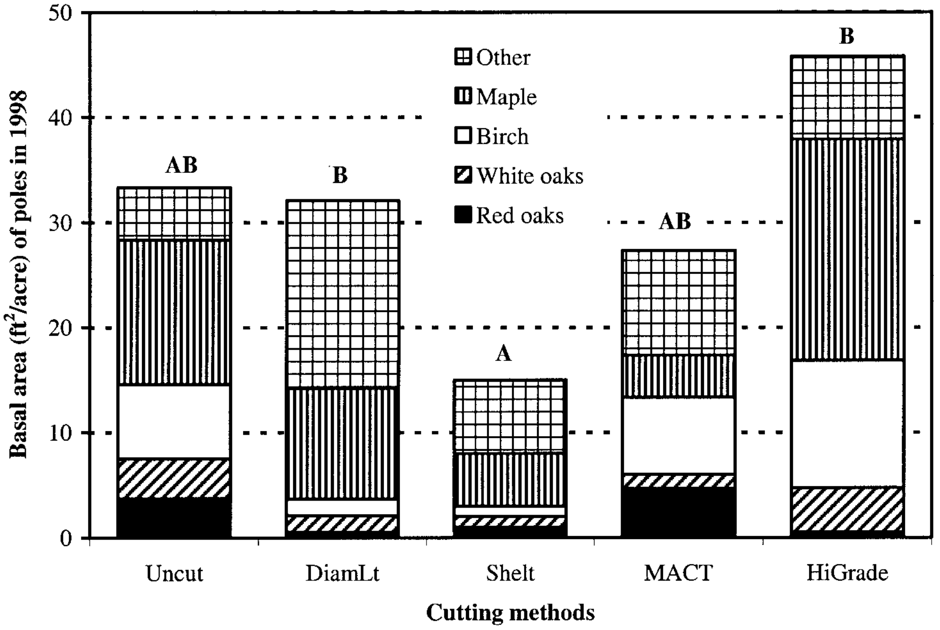

Figure 2. Basal area distribution (ft²/ac) of poletimber (4.5–10.9 in. dbh) 14–17 years after first cutting cycle. Basal area values with the same letter were not significantly different at $P \leq 0.05$. See Figure 1 for cutting method abbreviations.

Board-Foot Volume

Before the initial harvest, board-foot volumes (International ¼) averaged 8.4 mbf/ac, 69% in trees with butt-log grades of 1 or 2 (Table 3). Harvested volumes ranged from 3.2 mbf/ac on the multiaged crop tree plots to 8.2 mbf/ac on the high grading plot. Harvesting removed 71% of grade 1 and 2 trees on the diameter limit plot, and 50% on shelterwood and multiaged crop tree plots.

There was a significant difference among cutting methods in net annual board-foot growth (KW = 29.1, *df* = 4, $P \leq 0.001$) (Figure 3). The Tukey HSD pairwise comparisons indicated that board-foot growth on the high grading plots (36 bf/ac/year) was significantly lower than all cutting methods (199–244 bf/ac/year). This difference may become less pronounced in a few years as more poletimber grows into the sawtimber size class on the high grading plots.

Table 3. Distribution of board-foot volume (International ¼ Mbf/acre) by buttlog grade before and after two cutting cycles in a southern New England cutting method study. There was no harvesting on the forest preserve and high grading plots during the second cutting cycle.

Cutting method	Period	Grade 1	Grade 2	Grade 3	Local/ Cull	Total
Forest preserve/ uncut	Initial	2.5	3.0	2.4	0.4	8.3
	After 1st cut	2.4	3.0	2.4	0.4	8.1
	Before 2nd cut	5.5	3.2	2.8	1.2	12.6
	After 2nd cut	5.5	3.2	2.8	1.2	12.6
Diameter limit	Initial	3.5	2.8	2.6	0.8	9.5
	After 1st cut	0.6	1.2	1.9	0.5	4.2
	Before 2nd cut	3.9	1.4	2.3	0.5	8.1
	After 2nd cut	0.1	0.3	1.4	0.2	2.0
Shelterwood	Initial	3.8	2.6	2.2	0.5	9.1
	After 1st cut	2.2	1.0	0.9	0	4.1
	Before 2nd cut	5.4	1.5	1.0	0.1	8.0
	After 2nd cut	0	0	0	0	0
Multi-aged crop tree	Initial	0.9	2.6	2.6	0.1	6.2
	After 1st cut	0.8	1.1	1.2	0	3.0
	Before 2nd cut	3.3	1.9	1.3	0.6	7.2
	After 2nd cut	2.3	1.1	0.9	0.3	4.6
High-grading	Initial	3.3	3.4	1.1	0.5	8.2
	After 1st cut	—	—	—	—	—
	Before 2nd cut	0.2	0.3	1.3	0.1	1.9
	After 2nd cut	0.2	0.3	1.3	0.1	1.9

Although there was no significant correlation between total residual basal area and subsequent basal area growth, oak volume growth (Figure 3) was significantly correlated with oak residual basal area ($r^2 = 0.78$, $P \leq 0.001$). Oak species accounted for nearly all of the residual basal area (83%) and board-foot growth (97%) in the multiaged crop tree plots. Oak comprised over 60% of residual basal area and accounted for 90% of volume growth on the shelterwood and uncut plots. Although oak was less than half of the residual basal area on the high grading plots, oak accounted for more than 86% of volume growth.

Total board-foot volume (harvested volume + residual volume + growth) was significantly different among cutting methods (KW = 19.4, *df* = 5, $P \leq 0.002$) (Figure 4). The Tukey HSD pairwise comparisons indicated that total volume for the silvicultural clearcut (7.3 mbf/ac) was significantly lower than for uncut (12.3 mbf/ac), shelterwood (12.5 mbf/ac), and diameter limit cuts (13.0 mbf/ac).

Buttlog grades did not differ significantly among cutting methods prior to the initial harvesting (Table 4). Mean buttlog grade was 2.5 over all cutting methods. Mean buttlog grade of residual trees on the shelterwood plots (2.2) was significantly better than on diameter limit plots (2.7) after the first cutting cycle. In the interval between the first and second cutting cycles, mean buttlog grade improved for all cutting methods except forest preserve.

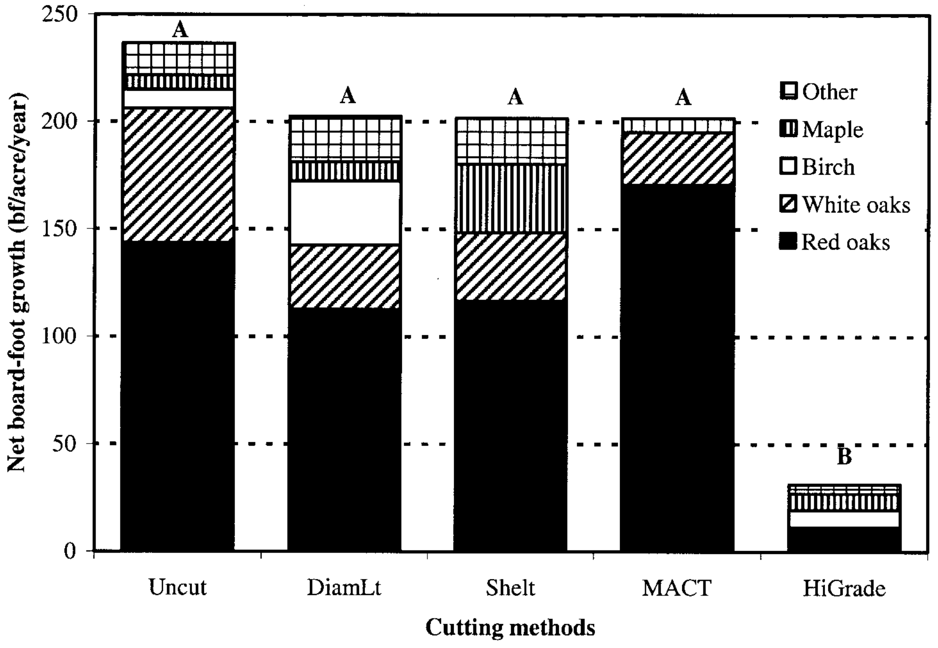

Figure 3. Net board-foot volume growth (International ¼ mbf/ac/year) by cutting method in a southern New England study. Growth values with the same letter were not significantly different at $P \leq 0.05$. See Figure 1 for cutting method abbreviations.

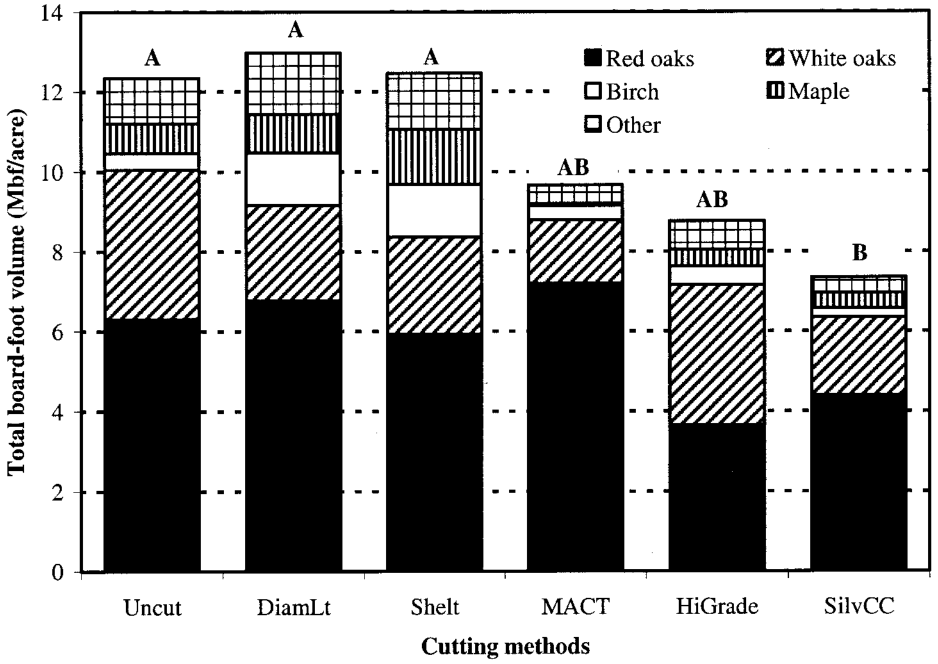

Figure 4. Total board-foot volume (International ¼ mbf/ac) 14–17 years after initial harvest by cutting method in a southern New England study. Total volume = harvested + residual + growth. Total volumes with the same letter were not significantly different at $P \leq 0.05$. Cutting methods: Uncut, forest preserve; DiamLt, diameter limit; Shelt, shelterwood; MACT, multiaged crop tree; HiGrade, high grading; and SilvCC-silvicultural clearcut.

After the Second Cutting Cycle

After the second harvest, multiaged crop tree management had notably higher board-foot volumes (4.6 mbf/ac) than the other partial cut treatment (Table 3). The diameter limit plots (2.0 mbf/ac) had only slight higher volumes than the high grading plots (1.9 mbf/ac). Species composition of residual trees differed among cutting methods after the second cutting cycle (Figure 5). Oaks, especially red oaks, remained the predominant species on both the forest preserve (62% of basal area) and multiaged crop tree plots (79%). In marked contrast, maple and birch accounted for the largest proportion of residual basal area on both the diameter limit (47%) and high grading plots (57%). Oak accounted less than one-quarter of residual basal area on these partially cut plots.

Table 4. Mean (standard error) buttlog grade before and after each cutting cycle by cutting method. There was no harvesting on the forest preserve and high grading plots during the second cutting cycle. Column values for each period followed by the same letter were not found significantly different using Tukey's HSD test at $p<0.05$.

Cutting method	First cutting cycle		Second cutting cycle	
	Before	After	Before	After
Forest preserve	2.3 (0.10) a	2.3 (0.13) b	2.4 (0.13) b	2.4 (0.14) b
Diameter limit	2.6 (0.11) a	2.7 (0.15) a	2.4 (0.15) b	2.9 (0.17) a
Shelterwood	2.3 (0.10) a	2.2 (0.15) b	2.0 (0.15) c	—
Multi-aged crop tree	2.6 (0.12) a	2.5 (0.17) ab	2.1 (0.17) bc	2.3 (0.18) b
High-grading	2.5 (0.11) a	—	2.9 (0.18) a	2.9 (0.17) a
Silvicultural clearcut	2.4 (0.10) a	—	—	—

Buttlog grade did differ significantly among cutting methods after the second cutting cycle (Table 4). Grade on the high grading and diameter limit treatments (2.9) was significantly worse than for both the forest preserve (2.4) and multiaged crop tree plots (2.3). There was a significant difference ($\chi^2 = 24.2$, $df = 9$, $P \leq 0.004$) among cutting methods in the amount of cull in pole sized trees (Figure 6). Not unexpectedly, the proportion of trees with 10% or more cull was highest in the high grading plots (70%). Quality of the residual trees actually increased on plots with the other partial cut methods. Diameter limit (34%) and multiaged crop tree (31%), than lower cull rates than the forest preserve plots (47%). There was no significant difference in board-foot cull rates among cutting methods for sawtimber trees ($\chi^2 = 14.1$, $df = 9$, $P \leq 0.117$).

Discussion

This research allowed direct comparison of distinct management practices on stand growth and yield in sawtimber oak stands over a 14–17-year period. Earlier recommendations not to thin in mature sawtimber stands were largely based on low thinning studies (Sander 1977, Hibbs and Bentley 1983). More recent studies have found that mature, sawtimber oaks respond well to high thinning or crop tree management (Beck 1986, Smith and Miller 1991, Meadows 1998, Perkey and Onken 2000, Ward 2002). Thus, these prescriptions can provide harvest income while simultaneously maintaining volume growth and high forest cover (albeit with different composition). This may be an attractive option for nonindustrial private forest owners with smaller parcels, as well as for managers of larger tracts.

As mentioned earlier, stocking was reduced to approximately 40% on the diameter limit and shelterwood plots and 30% on the multiaged crop tree plots. This study found that stand growth of sawtimber oaks (Figure 3) can be maintained at residual stocking far below B-level stocking without significant grade deterioration for residual trees (Table 4). Although mature sawtimber stands can maintain high volume growth over a wide of residual basal area, 40–100 ft^2/ac (Dale 1972, Marquis 1984, but see Roach and Gingrich 1968, Gingrich 1971), higher stocking levels have been advocated to reduce the loss of grade caused by epicormic branching (Sonderman 1984, Sander and Smith 1989, Marquis 1984). The present study suggests that in older stands, grade improvement caused by increased diameter growth more than offset any grade devaluation caused by new epicormic branching or logging damage (Table 4). This was marked true in the shelterwood and multiaged crop tree plots where vigorous trees were selected as residuals (Beck 1986, Meadows 1998, Ward 2002). Other studies also reported did not become worse following shelterwood harvests (Johnson et al. 1998) and deferment cutting (Miller 1996).

Although the purpose of a shelterwood is to initiate regeneration, we found benefits including: maintenance of high volume growth (Figure 3), grade improvement (Table 4), and income from the initial harvest. Other studies have demonstrated that volume growth can be maintained following shelterwood (Rudolph and Lemmien 1976), deferment or reserve tree cutting (Beck 1986, Smith et al. 1989), and crop tree management (Dwyer et al. 1987, Smith et al. 1994). The grade improvement can be attributed to both larger diameter (Rudolph and Lemmien 1976, Miller 1996, Johnson et al. 1998) and selection of vigorous residual trees (Beck 1986, Meadows 1998). Combined with the aesthetic appeal of the residual stand, these advantages indicate that a shelterwood prescription may be an amenable introduction to forest management for landowners who are hesitant to initiate harvesting on their property.

Silvicultural clearcutting was included to provide a contrast with total yield estimates for the other cutting methods. It is worth noting that total yield for the silvicultural clearcut was not significantly lower than for the high grading (Figure 4). The 14- to 17-year-old stands created by the silvicultural clearcut are entering a period of rapid cubic-foot growth (Dale 1972). Therefore, it is unlikely that total cubic-foot yield on high grading plots will significantly exceed that of the silvicultural clearcut.

Because the multiaged crop tree treatment simultaneously maintained stand volume growth (Figure 3) and a high proportion of oak in the residual stand (Figure 5), additional work is warranted on the long-term feasibility of this hybrid of crop-tree management with single tree selection. The accelerated loss of oak following other partial cutting methods was not observed on the multiaged crop tree plots. Indeed, the other cutting methods actually increased the proportion of nonoak species in the pole size class (Figure 2). Recruitment of new oak standards in the multiaged crop tree plots is probably related, at least in part, to the removal of nearly all of the poletimber (i.e., midstory trees) during each cutting cycle. The increased light on the forest floor resembles that after a shelterwood and allows established large oak saplings to develop rapidly.

The continued rapid volume growth on diameter limit plots after the first cutting removed many of the larger, faster-growing oaks was surprising. However, other studies have reported satisfactory volume growth after diameter limit cutting (Hutnik 1958, Miller and Smith 1991). However, to achieve economically viable harvests, it was necessary to lower the diameter limits for the second cutting

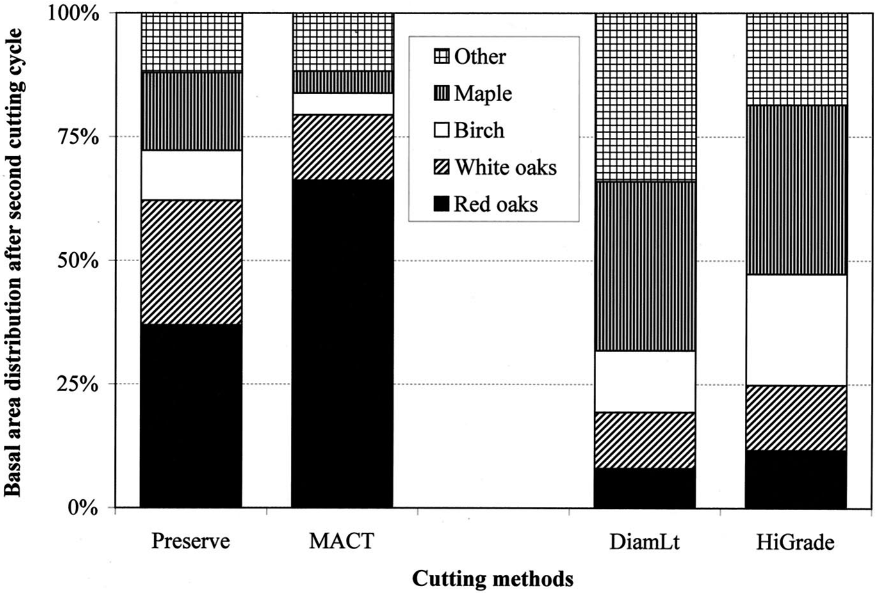

Figure 5. Distribution of residual tree basal area among species groups after the second cutting cycle in a southern New England study. See Figure 1 for cutting method abbreviations.

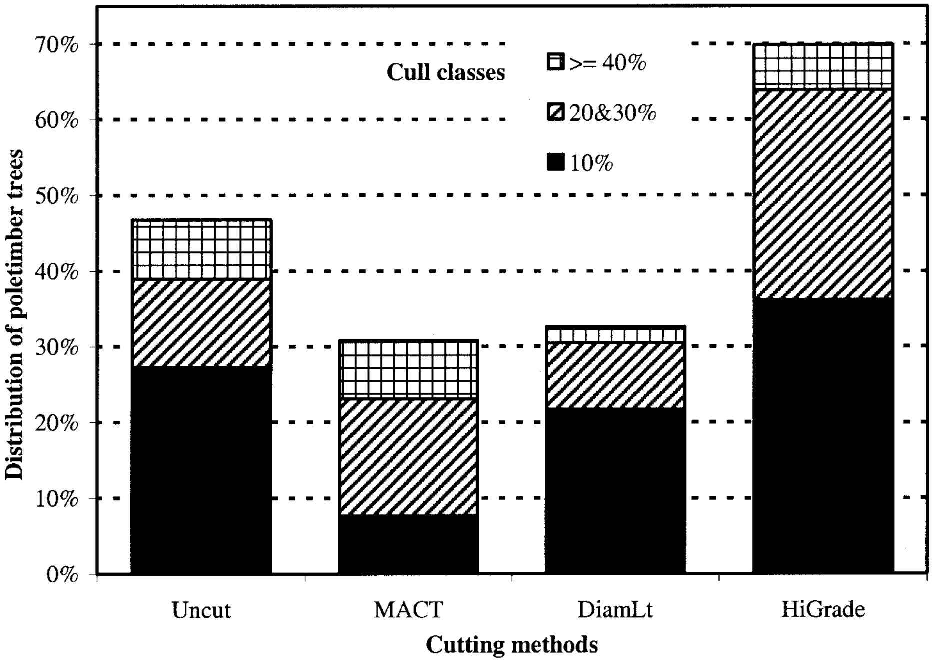

Figure 6. Distribution of cubic-foot cull classes in residual poletimber trees (4.5–10.9 in. dbh) by cutting method after the second cutting cycle in a southern New England study. Cull classes: 10%, trees with 10% cubic-foot cull; 20&30%, trees with 20% and 30% cubic-foot cull; 40%, trees with 40% or more cubic-foot cull. See Figure 1 for cutting method abbreviations.

cycle on two of the three plots (Table 1). As a consequence, residual stand structure after the second cutting cycle was similar to that for the high grading plots. Most oaks were removed during the second cutting cycle and the resulting stands were similar in both composition (Figure 5) and residual volume (Table 3) to the stands that had been high graded 14–17 years earlier. Therefore, it is likely that board-foot volume growth on the diameter limit plots will decrease to levels similar to those for the high grading plots (Figure 3).

Although high grading had an initially higher harvested volume, low quality of residual trees (Table 4, Figure 6), and depressed stand growth rates (Figure 3) indicate that this is not a viable option for long-term forest management. As with other studies that examined changes in species composition following partial cutting (Rudolph and

Lemmien 1976, Jokela and Sawtelle 1985, Abrams and Scott 1989, Ward 1991), we found high grading accelerated the conversion of stands from oak to mixtures of maple, birch, and other species with lower commercial and wildlife values (Figure 5).

For owners that do not require periodic income derived from the forest to pay property related costs, unmanaged forest preserves may be a viable option. Total volume (Figure 4) and annual growth rates (Figure 3) were as high as other management options examined in this study. Most of the volume remained concentrated on oak. Oak species accounted for high proportion of final basal area for both sawtimber (74%) and poletimber (23%). However, the forest manager and landowner should be cognizant that this method does incur some risk from potential losses due to natural mortality, weather (severe winds, ice), and insect or disease outbreaks.

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