Diameter-Limit Cutting and Silviculture in Northern Hardwoods

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The Situation

North American forestry has a long history of diameter-limit removals and other forms of selective cutting in uneven-aged stands (Kelty and D'Amato this proceedings). Its use increased among even-aged forests beginning in the 1980s as trees in naturally reforested stands on former agricultural sites and other kinds of second-growth stands reached sawtimber sizes (Nyland 1992). Other assessments of timber harvesting have more recently identified diameter-limit cutting as a widespread practice in many regions of northeastern North America (Fajvan et al. 1998; Pell 1998; Nyland 2000). Practitioners cite the ease of application (no marking or other close control over cutting), high first-entry yields and associated revenues (usually all the merchantable trees taken), and the higher rate of interest expected from removing all or most of the value from a stand. They usually do not cite any ecologic effects, changes in visual qualities as a consequence of the cutting, and effects on other non-market values. Further, arguments usually do not consider the long-term implications if used over multiple entries to a stand, but focus on a single cutting and what it initially brings to a landowner.

The traditional emphasis on financial aspects of diameter-limit cutting, compared to the silvicultural alternatives, begs answers to two key questions:

1. Does diameter-limit cutting result in greater long-term yields when used over multiple cutting cycles?
2. Will long-term revenues from stands operated by diameter-limit cutting exceed that from conventional silvicultural practices?

To address these matters I used simulation methods to compare diameter-limit cutting with crown thinning in even-aged stands, and with selection system silviculture for uneven-aged ones. The simulations included multiple consecutive entries to each test stand, and compared three examples for each stand condition.

Key Considerations for Even-aged Stands

Even-aged northern hardwood stands have a major component of shade-tolerant species and may include pure stands of sugar or red maple. Yet many also have trees of lower shade tolerance as well. As both kinds of stands develop, differentiation occurs in heights and diameters, within and between species. This commonly results in a wide spread of tree sizes, giving the diameter distribution a reverse-J shape. Such stands usually have a single canopy layer, with trees of both species groups in dominant and codominant positions. This differentiation in size among trees reflects unequal rates of development that has implications for management.

In cases with more than about one-third of the basal area in shade-intolerant species, stands commonly develop a two-layered structure. These highly stratified mixed-species stands often have a bi-modal diameter distribution, with separate segments for the dominant shade-intolerant species and another for the slower-growing shade-tolerant understory. Diameter growth will vary among trees within each species group, except that overtopped trees of the shade-intolerant species usually die early during stand development, leaving others mostly of upper-canopy positions and larger diameters.

Highly stratified stands require special consideration in their management. These might include appropriate removal of some species, and cutting of trees from only designated size classes. For example, if a stratified mixed-species stand had short-lived shade-intolerant species in the overstory (e.g., paper birch and aspen), cutting might appropriately remove those large trees before ones of the understory (e.g., sugar maple) reach operable sizes (see Leak 1999). When more long-lived species of low shade tolerance dominate the overstory (e.g., black cherry and white ash), but have begun to decline in vigor due to aging, cutting might appropriately reduce their numbers. Yet to insure adequate representation of these

Table 1.—Fifteen-year post-thinning diameter growth of sugar maple trees having different initial crown positions, Adirondack northern hardwoods (after Nyland et al. 1993).

Crown position	15-yr diameter growth
	Inches
Dominant	2.98
Codominant	1.95
Intermediate	1.36
Overtopped	0.69

species in the next rotation, some minimum stocking of well-dispersed individuals of good vigor must remain as a future seed source (e.g., Marquis 1994). In cases where the understory species has little commercial value (e.g., hophornbeam) or might eventually interfere with regeneration of more desirable trees (e.g., beech and striped maple), a type of reverse diameter-limit cutting (e.g., A or B grade thinning from below) might prove important as a site preparation measure prior to the end of a rotation. So due to these and other complexities of species composition, and their implications for long-term management, my assessment did not consider stratified mixed-species stands.

Table 1 shows the post-thinning diameter growth for sugar maple trees in a 70- to 75-yr old northern hardwood stands where shade-intolerant species comprise only about 15-20% of the basal area (after Nyland et al. 1993). Over the 15-yr observation period, codominant sugar maple trees grew at about 66% the rate of dominants, intermediates at 46%, and overtopped trees at 23%. Earlier, Marquis (1991) had shown a similar disparity among crown classes in mixed-species Allegheny hardwood stands. Further, differences between them increased as stands aged, particularly for the intermediate and overtopped trees. Such findings illuminate a major effect of diameter-limit cutting in even-aged stands, compared to crown thinning. The latter favors trees of upper-canopy positions, removing adjacent ones of lower vigor and poorer quality. It controls spacing between the residuals, and concentrates the growth potential of a site onto trees of the best grade and quality. Diameter-limit cutting just removes the best-growing trees (as indicated in Table 1).

Thinning also regulates the residual density to insure full site utilization and full net volume production until the next entry. Diameter-limit cutting simply removes the largest and most vigorous trees from even-aged stands without controlling the level of residual stocking or regulating the spacing between the trees left behind. Further, it makes no attempt to improve stand quality by removing trees of poor quality and grade from the residual size classes.

Effect of Diameter-Limit Cutting on Long-term Production from Even-aged Stands

To explore similarities and differences between crown thinning and diameter-limit cutting, I simulated the development of three real even-aged stands for three successive entries through time. The simulations started with the pre-cutting diameter distribution (1-in. classes) for each stand. For the diameter-limit cuttings I removed all trees ≥12 in. dbh, and simulated stand growth for an appropriate time until it would support another diameter-limit removal (15 yrs in most cases). The crown thinnings reduced stocking to 60% relative density, taking 2/3 of the cut among trees smaller than the median stand diameter (DM[1]), and 1/3 in trees above DM. The simulations projected development after each cutting by stand table projection, using movement percents for an appropriate cutting cycle based on remeasurement of trees in a thinned stand of similar species composition and degree of development. For neither type of cutting did the simulations add ingrowth of new trees to the stands, but in all cases I assumed that the cuttings controlled mortality. I simulated three entries for each pair of treatments, with the last one serving as a reproduction method to end the rotation.

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[1]DM reflects the diameter at the midpoint of the distribution of basal area among trees ≥6 inches dbh, using basal area per diameter class as a weighting factor in calculating the average diameter (see Marquis et al. 1992).

Table 2 shows initial conditions in the three test stands, and Table 3 the comparative levels of simulated sawtimber volume production from the different treatments in each one. It also shows that the diameter-limit cuts took no pulpwood at any entry. By contrast, thinning removed 10 to 11 cds/ac for the first entry to these stands, and additional pulpwood with each subsequent cut. Further, the thinning regimes provided 1.2 to 1.3 times more cumulative board-foot volume for the entire rotation. Quite important, they yielded 71%, 73%, and 74%, respectively, of the total sawtimber volume from trees at least 16 in. dbh (potentially Grade 1 trees). For diameter-limit cutting these proportions were 8%, 11%, and 13%.

Table 2.—Initial condition of three even-aged stands used for the simulations.

Stand	BA/acre	Number/ acre[a]	DM[b]	Relative density
				Percent
1	105	304	10.4	103
2	121	594	10.7	92
3	106	484	11.0	104

[a]Trees ≥1.0 inches d.b.h.
[b]The diameter at the midpoint of the distribution of basal area, for trees ≥6 inches d.b.h.

Effect of Diameter-Limit Cutting on Long-term Revenues from Even-aged Stands

Table 4 shows the value of simulated sawtimber yields, with stumpage price applied by tree diameter and grade, based upon the price of sugar maple lumber in 2003. The simulations assumed that each tree would have the highest grade possible for its diameter (Grade 3 for 12-in. trees, Grade 2 for those 13 through 15 in. dbh, and Grade 1 for trees ≥16 in.). Revenues from the thinning regimes exceeded those for diameter-limit cutting by 200%, 179%, and 176%, respectively, for the three stands. This reflects the greater proportion of cumulative volume from trees ≥16 in. dbh, and the higher stumpage value of those trees. Harvest revenues discounted to the time of the first entry (at 4%, 6%, and 8% rates of interest) had positive present net worth (PNW) values from both strategies. Generally, they were higher for diameter-limit cutting with discount rates in excess of 4%. This contrasts with the appreciably higher rotation-long sales revenues from the stands treated by crown thinning,

Table 3.—Comparison of sawtimber volume production between simulated diameter-limit cutting and crown thinning in three even-aged northern hardwood stands.

Stand 1	D-limit		Thinning	
Entry	Cut	Left	Cut	Left
	(*Bdft/ac*)		(*Bdft/ac*)	
1st	3,264	0	593	2,671
2nd	2,872	0	1,055	6,109
3rd	3,427	0	10,788	0
All	9,563		12,436[a]	

[a]1.30 times more sawtimber, plus pulpwood of 11.4 cds, 7.6 cds, and 21.0 cds for the three successive entries.

Stand 2	D-limit		Thinning	
Entry	Cut	Left	Cut	Left
	(*Bdft/ac*)		(*Bdft/ac*)	
1st	4.874	0	1,039	3,835
2nd	3,523	0	2,034	7,442
3rd	4,784	0	13,044	0
All	13,181		16,117 [b]	

[b]1.22 times more sawtimber, plus pulpwood of 11.1 cds, 7.5 cds, and 2.7 cds for the three successive entries.

Stand 3	D-limit		Thinning	
Entry	Cut	Left	Cut	Left
	(*Bdft/ac*)		(*Bdft/ac*)	
1st	4,787	0	1,056	3,730
2nd	2,990	0	2,462	6,223
3rd	3,534	0	10,496	0
All	11,311		14,014[c]	

[c]1.24 times more sawtimber, plus pulpwood of 9.7 cds, 3.5 cds, and 4.3 cds for the three successive entries.

indicating a need for landowners to choose between higher total cash flow from silviculture, or a higher discounted present worth of that revenue when the alternate rate of return exceeds 4% (real rate of return).

Key Considerations for Uneven-aged Stands

Uneven-aged stands have three or more age classes, with both the heights and diameters of trees related to their ages. Within each age class, some trees grow better than others. Yet available evidence (Eyre and Zillgitt 1953; Mader and Nyland 1984) shows that selection system cutting generally stimulates the growth of trees in all diameter classes, with greater absolute increases among the saplings and poles than for larger trees when the treatment reduces stand density to moderate or lower levels of stocking. Selection cutting removes the mature age class (generally specified by a threshold maximum diameter for the residual stand) to promote the regeneration of a replacement cohort. It also thins the immature age classes to leave specified numbers of each diameter (Nyland 1998), usually to conform to a structural guides like that proposed by Eyre and Zillgitt (1953) and Arbogast (1957) for northern hardwoods. The tending removes trees of the poorest quality and vigor, thereby upgrading the growing stock. By contrast, diameter-limit cutting simply removes all trees larger than some specified size. It does no tending of the immature age classes, nor does it control spacing and stocking levels to optimize growth and production.

Table 4.—Comparison of sawtimber value realized from simulated diameter-limit cutting and crown thinning in three even-aged northern hardwood stands.

Stand 1	D-limit		Thinning	
Entry	Cut	Left	Cut	Left
	(Dollars/ac)		*(Dollars/ac)*	
1st	1,823	0	271	1,552
2nd	1,168	0	588	4,034
3rd	1,396	0	7,925	0
Total	4,387		8,784a	

[a]2.00 times more sawtimber revenue, plus $240 from sale of pulpwood (@$6/cd).

Stand 2	D-limit		Thinning	
Entry	Cut	Left	Cut	Left
	(Dollars/ac)		*(Dollars/ac)*	
1st	2,665	0	585	2,080
2nd	1,577	0	1,306	4,902
3rd	2,202	0	9,638	0
Total	6,444		11,529b	

[b]1.79 times more sawtimber revenues, plus $128 from sale of pulpwood (@$6/cd).

Stand 3	D-limit		Thinning	
Entry	Cut	Left	Cut	Left
	(Dollars/ac)		*(Dollars/ac)*	
1st	2,620	0	496	2,124
2nd	1,363	0	1,149	4,392
3rd	1,623	0	7,864	0
Total	5,606		9,857c	

[c]1.76 times more sawtimber revenue, plus $105 from sale of pulpwood (@$6/cd).

Past simulation studies of uneven-aged silviculture in northern hardwoods showed the importance of matching the cutting interval to the level of residual stocking (Hansen and Nyland 1987). Time must allow sufficient regrowth to replenish the volume. Also, cutting optimizes sawtimber volume production when it balances the age classes, generally by removing excess trees from the immature classes (cutting back to the target residual diameter distribution as noted above). Taking these steps also insures consistency in the structural conditions through time (Hansen and Nyland 1987), and in volume production through multiple entries to a stand (Nyland 1998).

Effect of Diameter-Limit Cutting on Long-term Timber Production and Value from Uneven-aged Stands

For the assessment of similarities and differences between selection system and diameter-limit cutting, I used the uneven-aged stand simulator by Hansen (see Hansen and Nyland 1984). The simulations included three real uneven-aged stands that had received a single diameter-limit cut, and three others following a single selection system cutting as described above (see Nyland 2005). Simulations started with the observed post-cutting diameter distribution (1-in. classes) for each stand. Then I grew them until stocking increased sufficiently for a second entry. Thereafter, I simulated the original cutting strategy over multiple entries at the designated interval for a 90- to 100-year period of time.

Diameter-limit cutting removed all trees ≥14 in. dbh from two stands, and ≥16 in. in one other. The selection system cutting used 23 in. as the diameter for financial maturity, and reduced overall stocking to 75-80 ft^2/ac. The simulator accounted for ingrowth of new age classes, and mortality as appropriate. Growth rates reflected changes previously observed in partially cut uneven-aged northern hardwood stands (Hansen and Nyland 1987).

Table 5 shows the sawtimber yields from each stand, and Table 6 the associated stumpage values. These reflect the volume harvested during the 90- to 100-yr periods, plus that in the residual stand after the last entry. Volume data indicate that selection system resulted in 91 to 93% of the volume coming from trees ≥16 in dbh (potentially Grade 1). The diameter-limit stands yielded 41%, 60%, and 89%, respectively, from trees of that size. That affected the realized values. A comparison of the diameter distributions across stands indicated that differences in yields associated with each cutting treatment reflect their structural attributes of the stands, and particularly in the abundance or shortage of poles that moved into sawtimber status during each cutting cycle. The third diameter-limit stand had large numbers of small trees, and their movement out of the pole class sustained a higher level of sawtimber production than in the other two diameter-limit cases. Selection system Stands A and B had initial deficiencies in the pole classes, and the limited number that moved out of pole size kept ingrowth to sawtimber below the level observed for Stand C.

Differences in cutting cycle lengths between stands complicates any comparison across treatments. But Table 7 converts the production to annualized values. It shows that selection system resulted in an average production of 52 bdft/ac/yr more than the diameter-limit cuts, with

Table 5.—Comparison of sawtimber volume production between simulated diameter-limit cutting and selection in uneven-aged northern hardwood stands (after Nyland 2005).

			Realized yield (board feet/acre)[a]		
Stand	Total years	Cutting interval	Total	From trees 16”+	% 16”+
D-14[b]	100	20	26,284	10,718	41
D-16	100	2519,503		11,656	60
D-14	90	3018,465		16,450	89
Sel A	90	1523,618	21,412	91	
Sel B	90	1523,671	22,079	93	
Sel C	90	1526,454	24,277	92	

[a]For entire simulated time, including ending residual stand.

[b]D-14 took all trees ≥14 inches d.b.h., and D-16 those ≥16 inches d.b.h.

Table 6.—Comparison of value realized between simulated diameter-limit cutting and selection in uneven-aged northern hardwood stands (after Nyland 2005).

			Realized value[b]
Stand	Total years	Cutting interval	Total
D-14	100	20 yrs	$11,173
D-16	100	25 yrs	$11,713
D-14	90	30 yrs	$12,913
Sel A	90	15 yrs	$15,268
Sel B	90	15 yrs	$15,588
Sel C	90	15 yrs	$17,070

[a]D-14 took all trees ≥14 in. dbh, and D-16 those ≥16 in. dbh.

[b]For entire simulated time, including ending residual stand.

a $53/ac higher annual value growth. The simulations also showed more consistent levels of annual volume and value production across three selection system stands than following diameter-limit cutting. Harvest revenues discounted to the beginning of the 90- to 100-yr simulation period (at 4%, 6%, and 8% rates of interest) had positive PNW values from both strategies. For all rates, the diameter-limit cutting had a lower PNW. This mimics the higher century-long revenues from stands treated by selection system.

Table 7.—Comparison of annualized sawtimber and value production between simulated diameter-limit cutting and selection in uneven-aged northern hardwood stands (after Nyland 2005).

Stand	Total years	Cutting interval		Annualized production[a]	
				Bdft	Dollars
D-14	100	20 yrs		263	112
D-16	100	25 yrs		195	117
D-14	90	30 yrs		205	143
			Average	221	124
			SD	36.7	16.6
Sel A	90	15 yrs		262	169
Sel B	90	15 yrs		263	173
Sel C	90	15 yrs		294	190
			Average	273	177
			SD	18.2	11.2

[a]Harvested plus that left standing after last cutting.

Similarities and Differences

None of the simulations accounted for losses of trees broken off during logging, or variations in tree growth associated with uniform or patchy spacing between residual trees. For the even-aged stands, I assumed that trees starting off in poor crown positions would increase in vigor as they grew larger, and radial increment would also increase accordingly. For the uneven-aged stands, I assumed that trees left after both types of cutting would provide adequate seed to regenerate a new cohort of desirable species following each entry, and that cutting would stimulate the growth of trees equally after diameter-limit and selection system cutting. For both stand types, I assumed that trees would have the highest grade for their diameter, and that neither epicormic branching or damage from logging or other causes would affect their value. Stumpage prices reflect the value realized by removing the entire sawtimber portion of a felled tree (stump height to a 8-inch top diameter as specified in the volume table), and assumes that all trees have no scaling deductions. These assumptions simplified comparisons across cutting strategies.

Findings from the simulations indicate that an initial diameter-limit cutting in the simulated even-aged stands (removing all trees ≥12 in. dbh) took out 4.5 to 5.5 times more sawtimber volume, and that resulted in 4 to 5 times more first-entry revenues. For the entire rotation (three entries), diameter-limit cutting yielded only about 80% as much volume as crown thinning, with only 9% to 14% of it from high-value trees (≥16 in. dbh). For these even-aged stands, it generated only 50% to 55% of the long-term revenues realized from the silvicultural systems employing crown thinning. Discounted harvest values from both strategies had a positive PNW at 4%, 6%, and 8% rates of interest (the range tested).

For the simulated uneven-aged northern hardwood stands, diameter-limit cutting that removed trees ≥14 or ≥16 in. dbh took out more volume and generated more harvest revenues during the first entry. Each diameter-limit cutting also left less residual volume, with stands having only 4 to 34% as much residual growing stock value as the selection system examples. For the 90- to 100-year simulation periods, diameter-limit cutting resulted in about 80% of the volume realized by selection system silviculture, including 1.5 to 2 times less yield from high-value sawtimber trees (≥16 in. dbh). Annualized revenues were only 70% of that from the simulated selection system stands. Discounted values (harvested, plus residual following the last cutting) from both strategies had a positive PNW at 4%, 6%, and 8% rates of interest (the range tested).

Overall, the simulations indicated that diameter-limit cutting over multiple entries (each time removing all trees ≥12 in. dbh from the even-aged stands, and those at least 14 or 16 in. from uneven-aged ones) will result in less realized sawtimber volume, fewer large-diameter sawlogs, and lower long-term revenues. Based on the higher sawtimber volume initially taken from a stand, diameter-limit cutting will prove more lucrative with the first entry into both stand types, but particularly when it removes all the sawtimber trees from even-aged stands at intermediate stages of development. Coupling the yield from excess pulpwood- and sawtimber-size trees will make crown thinning in even-aged stands commercially feasible. As long-term strategies, both approaches should have a positive PNW for interest rates of 4% through 8% (the range tested) when used in both even- and uneven-aged stands, at least under the conditions simulated for this comparison. Among uneven-aged northern hardwoods, selection system silviculture will give more consistent yields and values across stands. For both even- and uneven-aged stands, silviculture will provide a higher cash flow over the long run.

The simulations did not assess the ecologic effects of either cutting strategy, or the ways they influenced an array of non-market values. Yet users normally promote diameter-limit cutting based on the perceived advantage it has for providing greater harvest volume and higher revenues. The simulations reported here indicate that the long-term benefits from silviculture exceed the short-term gains from diameter-limit cutting, both in even- and uneven-age northern hardwood stands. That makes silviculture preferable for long-term sustainable forestry.

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